State-of-the-art analysis of the pedagogical underpinnings of open science, citizen science and open innovation activities

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INTEGRATING OPEN AND CITIZEN SCIENCE INTO
ACTIVE LEARNING APPROACHES IN HIGHER EDUCATION

State-of-the-art analysis of the pedagogical underpinnings of open science, citizen science and open innovation activities

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Abstract:	The document corresponds to O2A1 of the INOS Project. This state-of-the-art analysis elaborates on the current state of knowledge on learning design in open science, citizen science, and innovation activities, in order to improve their pedagogical value. This includes reporting on the different types of activities, the learning design of these activities, and the learning outcomes of these activities.

Keyword list:	Open knowledge; open science; citizen science; open innovation; pedagogy; learning design

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	Name	Short Name	Country
1	Aalborg University	AAU	Denmark
2	Tallinn University	TU	Estonia
3	Web2Learn	W2L	Greece
4	University of Oulu	UO	Finland
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List of Abbreviations

The following table presents the acronyms used in the deliverable in alphabetical order.

Abbreviations	Description
CBI CERN	Challenge Based Innovation @IdeaSquare (European Organization for Nuclear Research)
HEI	Higher education institutes, including academic libraries
MOOC	Massive Open Online Course
NIISS	The National Institute of Invasive Species Science
OER	Open educational resources
OEP	Open educational practices
Open ILab	Open Innovation Laboratory @*Tecnológico de Monterrey*
SOTA	State-of-the-art analysis

Executive Summary

Open science (including citizen science) and open innovation activities are transparent, accessible, shareable and open to participation. Open practice improves the quality of scientific and innovation outputs, as well as promote public engagement with science and technology, openness and active citizenship. Learning plays a key role in enabling open participation in open science and open innovation activities, and in improving the quality of their outputs. Therefore, the educational, scientific, innovative and social impact of these activities would be optimised if the learning components were grounded with a solid pedagogy. As many HEIs are involved with organising such activities, the INOS Project aims to improve their design to help enhance the impacts of these endeavours. This SOTA analysis assesses the current status of learning design in open science/innovation learning activities, in view to its improvement.

Twenty-four case studies were analysed. Based on our case selection, there are many possible types of open science activities with a learning component. Despite the diversity, collective analysis of the case studies revealed groups of activities with similar learning goals. Approaching activities by their learning goals is important for organisers, since these goals ultimately shape activity design. Popular knowledge gaps that open science/innovation activities aim to address include:

1. Knowledge or awareness of a particular topic (ubiquitous to all activities)
2. Soft and technical skills needed for proper and open science/innovation practice
3. Knowledge of the scientific inquiry method
4. Open data skills

Learners can be from within HEI communities (e.g. researchers, university students) as well as outside HEI communities (e.g. general public, school students, industry members). Activities can also be conducted for these groups separately or together. Participants are sometimes given agency to be part of the learning design themselves through project-based learning approaches. However, there is the potential to improve participant involvement in learning design at the planning stage and through the collection of learner responses.

From the case studies, four main learning approaches were identified: project-based learning, inquiry-based learning, collaborative learning and blended learning. Learning approaches are often combined and adapted to suit the learning goals and objectives. Each approach has its benefits to open science/innovation activities. For example, project-based learning is good for developing innovation/collaboration skills, which are important for open science/innovation practice. Beyond this study, informal science learning (i.e. learning by participation) is a common learning approach used in many citizen science activities. However, participation alone is not sufficient to ensure learning. It is argued that formal learning design should be adopted to better deliver this goal. As done by the citizen science case studies included in this report, a natural method to do so is to embed participation in citizen science activities into an inquiry-based learning format. Other pedagogical aspects described in this report include learning settings, and learning tools and resources.

Overall, there is lack of information on learner responses of open science/innovation activities. To make future improvements to teaching practices in open science/innovation activities, it is important for more activities to collect learner responses (e.g. feedback, learning assessments, learner analytics and evaluation). There is also limited literature on the pedagogies of these activities. Based on the available information on these case studies, motivators of learning in open science/innovation activities include active learning, authenticity, learner-centred learning, the use of technology, personal mentorship and guidance from experts. Challenges of learning include initial difficulties for participants to learn unfamiliar open skills, and that significant time and effort may be required to develop a pedagogically-sound open science/innovation activity.

1 Introduction

1.1 The role of learning in open science, citizen science and open innovation activities

Open science (including citizen science) and open innovation activities are scientific and innovation activities that are transparent, accessible, shareable and open to participation. Open practice improves the quality of scientific and innovation outputs, especially in the face of solving complex multidimensional issues such as climate change. Open science/innovation also promote public engagement with science and technology, openness and active citizenship. As formal settings of research and innovation, higher education institutes (HEIs, including academic libraries) are increasingly involved with organising such open activities.

Many open science/innovation activities involve some form of learning or knowledge transfer. Often, activities are used to improve public knowledge on important topics and skills. For example, many citizen science activities are designed to advocate environmental awareness or other contemporary causes. Events such as hackathons, datathons, service jams, knowledge cafés, fablabs, game labs and innovation sprints are also commonly held to improve public literacy on important 21st Century skills.

Learning also occurs when stakeholders of different backgrounds (across fields, sectors or communities) collaborate on a project. Participants thus need to acquire new technical and soft skills to facilitate the collaboration. For instance, when citizens or school children are engaged to participate in or conduct their own scientific research, they need to first understand the scientific inquiry process and acquire relevant technical scientific skills. In another scenario, when a multidisciplinary group of researchers is collaborating with non-university-based members to innovative a new product, all stakeholders need to practice collaboration soft skills to navigate the project.

Therefore, learning plays a significant role in the success of open science and open innovation activities. It is the INOS Project's position that the overall educational, scientific, innovative and social impact of these activities would be optimised if the learning components were grounded with a solid pedagogy. Currently, there is the opportunity to expand and improve the HEI curricula of open science/innovation activities, and by doing so, enhance the impact of these endeavours.

The purpose of O2 is to develop a learning design framework for pedagogically-sound open science/innovation learning activities organised by HEIs. As the first step, this O2A1 state-of-the-art (SOTA) analysis assesses the current status of learning design in open science/innovation learning activities and its pedagogical value, in view to its improvement. This assessment includes reviewing learning approaches by such activities, and identifying their strengths and challenges. Activities containing elements in science/innovation, openness and education are included as case studies.

This document reports on:

- The different possible types of open science/innovation learning activities (as observed from the selected case studies).
- The learning design of open science/innovation learning activities, including learning goals, learning objectives, learning implementation, as well as tools and resources.
- The learning outcomes (strengths and challenges) of open science/innovation learning activities.

1.2 Open concepts in knowledge

Open knowledge broadly refers to any knowledge (either embodied in artefacts, in social practices, or in research outputs) that is freely circulated – without any legal, technological or social restriction (Open Knowledge Foundation, n.d.).

Open science is "the practice of science in such a way that others can collaborate and contribute, where research data, lab notes and other research processes are freely available, under terms that enable reuse, redistribution and reproduction of the research and its underlying data and methods" (FOSTER Plus, n.d.). **Open science** is often used as a broad, umbrella term for various movements that removes barriers and enables the sharing of output, resources, methods or tools, and from any stage of the research process. Thus, examples of open science include open access to publications, open research data, open source software, open collaboration, open peer review, open notebooks, open educational resources, open monographs, citizen science, or even research crowdfunding (de la Fuente, n.d.). We consider social science to be contained within the realm of open science, since social science knowledge is also generated by research.

Within open science is the practice of citizen science. In **citizen science**, "a broad network of people collaborate. Participants provide experimental data and facilities for researchers, raise new questions and co-create a new scientific culture. While they add value, volunteers acquire new learning and skills and gain a deeper understanding of the scientific work in appealing ways. As a result of this open, networked and transdisciplinary scenario, science-society-policy interactions are improved, leading in turn to a more democratic research based on evidence and informed decision-making" (Fermín Serrano Sanz, Holocher-Ertl, Kieslinger, García, & Silva, 2014). Citizen Science is one of the eight priorities identified from the European Open Science Agenda (European Commission, 2018, p. 6).

Open innovation involves "the innovation process to all active players so that knowledge can circulate more freely and be transformed into products and services..." (European Commission, 2016, p. 11). In contrast to silo mentality, open innovation involves the flow of knowledge beyond the boundaries of a single organisation, with a high degree of cross-border organisational collaborations, such as between end-users, policy makers, industry and academic institutions (Chesbrough & Crowther, 2006; Simeone, Secundo, & Schiuma, 2017). The advantage of open innovation is that it stimulates the recombination of prior knowledge elements into novel outputs (Savino, Messeni Petruzzelli, & Albino, 2017). These outputs include products, technologies and services.

The principle of open innovation is commonly applied in business, design and technology, but is also indiscriminately related to science. Multidisciplinary and multisector collaboration is key for scientific progression and development in this era of wicked problems such as climate change (Hautamäki & Oksanen, 2016). Therefore, open innovation as a process is also inherent to problem solving in open science. When successful, these solutions can produce innovative outputs and products. Because of the overlapping principles, this report does not dwell upon making distinctions between open science and open innovation activities, especially since many activities have elements of both.

1.3 Open concepts in education

Openness in education is a tandem manifestation within the larger open knowledge movement (Bliss & Smith, 2017; Peters & Roberts, 2016; Wiley, 2006). There are multiple interpretations of what "openness" entails in education, including 1) open admission, 2) open as free, 3) open educational resources, and 4) open educational practices (Cronin, 2017).

The "open admission" interpretation refers to open-door academic policies where there is no entry requirement to institution-based learning – such as in open universities (Daniel-Gittens, 2016). The "open as free" interpretation refers to educational resources that are available publicly at no financial cost to the learner. The internet is a major facilitator of free resources, which can range from YouTube videos to Massive Open Online Courses, or MOOCs (Moe, 2015). With access, anyone can theoretically be a learner.

"Open educational resources" (OER) expands the interpretation further by including resources that are not only free in terms of financial cost, but that are also available for reuse, modification and sharing without the need to pay for royalties of licensing fees (Butcher, 2015; Open Education Consortium, n.d.; Wiley, n.d., 2009; Wiley, Bliss, & McEwen, 2014; Winn, 2012). This is typically achieved under the Creative Commons license (Wiley, n.d.). The ability to use and modify content is important for education, as it allows the adaptation of educational material for the intended learners (Open Education Consortium, n.d.).

While OER focuses on the openness of educational content, the "open educational practices" (OEP) interpretation shifts emphasis towards open-style practices in learning and teaching. The Open Educational Quality Initiative (OPAL) defines OEP as "practices which support the (re)use and production of OER through institutional policies, promote innovative pedagogical models, and respect and empower learners as co-producers on their lifelong learning path. OEP address the whole OER governance community: policy makers, managers/ administrators of organisations, educational professionals and learners" (The OPAL Initiative, 2011). After OER, OEP can be considered as the next phase of unlocking the full potential of open-style education, where OER are actively used to improve learning experiences and innovate educational scenarios (Camilleri & Ehlers, 2012; Ehlers, 2011; Paskevicius & Irvine, 2019; The OPAL Initiative, 2011).

OEP encompasses or is closely related to a number of other open-themed practices and pedagogical approaches simultaneously inspired by the larger open movement. As collated by Cronin (2017), this includes open scholarship (Veletsianos & Kimmons, 2012a; Weller, 2011), networked participatory scholarship (Veletsianos & Kimmons, 2012b), open teaching (Couros & Hildebrandt, 2016), open pedagogy (DeRosa & Robinson, 2017; Hegarty, 2015; Rosen & Smale, 2015; Weller, 2014), critical digital pedagogy (Stommel, 2014). OER-enabled pedagogy is another recently proposed practice (Wiley & Hilton, 2018). Most importantly, these ideas share the principles of open resources, open teaching, sharing, and networked participation (Cronin, 2017).

All four interpretations of "openness" in education are relevant to the aim of the INOS project. It is important for our findings to enhance education that is open to society (i.e. "open admission" and "open as free") and that uses openly-available educational material (i.e. OER) and open-style teaching and learning practices (i.e. OEP). Therefore, this report defines **open education** as education that is open admission, open as free, and utilizes OER and OEP.

1.4 Scope

This assessment includes reviewing learning approaches in existing or recent open science/innovation activities and identifying the challenges when attempting to assess learning in such activities. Activities containing elements in science/innovation, openness and education were considered as case studies. These broad criteria were used because there is a wide variety of activities that can be considered as educational open science/innovation activities.

We were particularly interested in activities that adopted a systematic method to accommodate at least the first two steps of the "design-implement-evaluate" learning process (i.e. learning design). Thus, the selected case studies are situations where learning was an intentional output and there was evidence of learning being designed (e.g. a lesson plan). For our selection and analysis, it was also necessary that the learning design was documented in detail and made available in the literature or via desktop research.

Activities that did not meet these criteria were not included for this study, as there would be insufficient pedagogical information for analysis here. As experienced by the author, it was difficult to source learning design documentation of open science/innovation activities. One possible reason is that this information is not regularly documented and made public, despite its pedagogical advancement value. It is also possible that learning design of open science/innovation activities are inconsistently conducted. For example, while there is an abundance of interesting and creative citizen science initiatives, the teaching strategy of many of these activities is limited to learning by participation (i.e. informal learning). Many informal learning scenarios tend to lack planned pedagogy and therefore offer insufficient information for our assessment of pedagogical practices.

Twenty-four case studies were finally selected, representing a diverse range of activities. Activities with natural/physical science, engineering, multidisciplinary innovation (including arts/science) and data science (including social science data) topics are represented by our case studies. However, because of insufficient pedagogical information, citizen science activities engaged with more artistic and historical topics are not as represented in our study set (e.g. activities that crowdsource transcription of historical literature) and is an available opportunity for future research.

As pedagogical information on open science/innovation activities were generally limited, case studies organised by both HEIs and non-HEIs were included as case studies. The amount of available information for each case study also highly varies. Case studies with more available information were inadvertently described and discussed more than those with less information published. The amounts of description and discussion of certain case studies are not a reflection of the importance or success of these activities.

1.5 Audience

This report is targeted towards HEIs wishing to enhance the educational and social impact of their open science/innovation activities. This report may also be of interest to all stakeholders wishing to understand the current pedagogical practices in open science and open innovation initiatives, and their implications for future ones. The audience includes higher education management, academic and library staff, students, policy makers, funding bodies, business stakeholders, European and international networks for training and skills related to open science and open innovation.

1.6 Structure

The structure of the document is as follows:

- Section 2: Methodology
  - Provides further details on the research questions and the SOTA analysis procedure.
- Section 3: Findings
  - Presents findings of the SOTA analysis.
- Section 4: Discussion
  - Discusses the findings in terms of the research questions.
- Section 5: Conclusion and summary
  - Summarises the SOTA report.

2 Methodology

2.1 Research questions

This SOTA analysis was guided by its aim *to identify the current state of knowledge on learning design in open science/innovation activities, in order to improve their pedagogical value*. The following research questions were developed:

RQ1. What are the characteristics of educational open science/innovation activities observed?
RQ2. How is learning designed in recent open science/innovation activities?
RQ3. What are the learner responses resulting from activity design decisions?

Information responding to these questions were gathered from selected case studies of open science/innovation activities. RQ1 aims to establish the various types of activities, and resolve shared characteristics of an educational open science/innovation activity. RQ2 involves the exploration of the learning design agents, learning objectives and goals, pedagogy, learning assessment, and tools and resources. Learning objectives are defined as specific, measurable competencies that can be assessed to determine if learning goals have been achieved. Learning goals refer to higher-order, overall ambitions educators have for learners (The Derek Bok Center for Teaching and Learning, 2019). RQ3 helps describe the learner responses and challenges that result from learning design decisions. Sources of learner responses include learning feedback, assessments, learner analytics and evaluation (Dalziel et al., 2016).

The research questions above were guided by the principles of Learning Design. Learning Design is a method to describe a learning and teaching process, so that these ideas can be shared with, and adapted by, other educators (Dalziel et al., 2016). The purpose of Learning Design is in concordance with the aim of O2 and the overall INOS project, and so is a very applicable format to structure this report.

2.2 Identifying relevant sources

Sources describing the pedagogical underpinnings of various open science/innovation activities included peer-reviewed articles, reports, documents and webpages. Several methods were used to locate relevant sources.

First, a scoping literature review (Arksey & O'Malley, 2005; Levac, Colquhoun, & O'Brien, 2010) was conducted, since such systematic ways of designing learning are often reported in scientific publications. Multiple research queries were made in Scopus, ProQuest and Google Scholar (Table 2.1). Multiple research strings were required due to the wide interpretation of terms within open science/innovation and education – it was found that searches using specific search terms produced more relevant results. Additional sources were gathered via the snowball method of searching the references of key sources. The selection of "citizen science", "open data", "open innovation" and "living labs" as primary search terms was made because they were key terms evident from the initial general search for "open science" activities. As pedagogical information on open science/innovation activities were generally limited, case studies organised by both HEIs and non-HEIs were included as case studies.

Case studies gathered for O1 of the INOS Project (Zourou & Tseliou, 2020) were also considered as case studies. However, not all O1 case studies could be included in this report, due to differences in selection criteria.

Case studies gathered from the literature review were supplemented with desktop research to discover information that have not been reported in the literature. The same research strings in Table 2.1 were used in Google Search. In addition, other members of the consortium independently searched for and contributed resources. Citizen science activities were also explored through the citizen science project databases Zooniverse (https://www.zooniverse.org/), nQuire (https://nquire.org.uk/), Österreich forscht (https://www.citizen-science.at/), SciStarter (https://scistarter.org/) and Citizen Science Portalen (https://citizenscience.dk/).

Table 2.1 – Research strings used to identify relevant studies.

Activity type	Research string
General	*("open science") AND (pedagogy) OR (learning) OR (education) OR ("learning design")*
Citizen science	*("citizen science") AND (pedagogy) OR (learning) OR (education) OR ("learning design")*
Open data	*("open data") AND (pedagogy) OR (learning) OR (education) OR ("learning design")*
Open innovation	*("open innovation") OR ("living labs") AND (pedagogy) OR (learning) OR (education) OR ("learning design")*

2.3 Case study selection

Using the methodology of Section 2.2, a total of 130 scientific publications were gathered. Duplicates, papers covering theoretical models, reviews, meta-analyses and other papers lacking relevant information were excluded. Selected case studies of open science/innovation activities needed to provide descriptions of learning design and orchestration. As explained in the Section 1.4, open science/innovation activities that have no documentation of pedagogical consideration could not be included in this SOTA analysis – this criterion proved to be the biggest limiting factor for selecting case studies. A final selection of 24 case studies gathered from across the scoping review and desktop research.

2.4 Charting the data

Descriptive information and elements of learning design were used as variables to extract information from each case study. Data charting was an iterative process where variables and data were continually extracted and updated. Throughout the charting data process, other members of the consortium were consulted for suggestions and input.

Final variables include: organiser, organiser type, activity scale, elements of openness, field, location, participants, years active, learning goals, learning approaches, learning design agents, tools and resources, and learner responses.

To present the findings, open science/innovation activities were grouped by shared primary learning goals and discussed separately. This allowed the comparison of the different pedagogical approaches used by separate case studies to achieve similar learning goals. Three sections were established:

1. Activities for developing open collaboration in science and innovation
2. Citizen science activities for inquiry learning
3. Activities for open data training and innovation

The different types of learning goals within each group are discussed separately in their individual sections in Section 3.

2.5 Collating, reporting and summarising the results

The charted case studies were compared and analysed for theme groupings and trends (i.e. qualitative thematic analysis). Analysis was first conducted by category (i.e. general science/innovation education activities, citizen science activities for inquiry learning, open data upskilling activities) – see Findings. All information was then consolidated again for final analysis in the Discussion, which responds to the research questions. Brief outlines of each case studies are provided in Annex A.

2.6 Consultation

Throughout the development of this report, all members of the consortium were consulted for suggestions and input. Preliminary drafts of this report were shared with all parties of the consortium. The final draft of this report was peer-reviewed by TU.

3 Findings

3.1 Overview of case studies

Twenty-four diverse cases of open science/innovation activities were analysed (an outline of each case study is provided in Annex A). Case studies were found from Australia, Austria, Denmark, France, Ireland, Italy, Mexico, Norway, Russia, Rwanda, Spain, Switzerland, UK and USA. Two case studies (**iSCAPE Living Labs** and **ODEdu: Open Data Education**), as international Erasmus+ and EU Horizon 2020 initiatives, each carried out activities in multiple European countries. Online-based case studies are considered international, due to their worldwide access for participation.

Activities were organised and co-organised by developers, government departments, government research organisations, libraries, museums, science centres, non-profit organisations, public initiatives, public schools, research/developer consortiums, a large research institute (CERN – the European Organization for Nuclear Research), universities, and a humanitarian aid agency (UNHCR – The United Nations High Commissioner for Refugees). Participants include librarians, the general public, refugees, researchers, school students, and university students. School and university students were the primary participants for most of the case studies.

Activities also varied in time duration and effort. Some activities were conducted within a day (e.g. short projects integrated into a school or university lesson), while others were long projects requiring a few days to a few weeks to complete (e.g. activities involving days or weeks-long citizen science data collection periods). There were also some open science/innovation courses that took a month to six months to complete. More than half of the case studies were initiated since 2010. The longest-running initiative is **Saltwatch** (now under **Waterwatch** Victoria), which began in 1987 (Pfueller, Innes-Wardell, Skondras, Marshall, & Kruger, 1997). Most initiatives are still active and ongoing.

Fields include Ecology, Design and Engineering, Environment, General Science, and Open Data. There is a clear dominance of natural science fields within our selection, with six Ecology and five Environment activities, which also reflects the overall abundance of Ecology/Environment citizen science activities beyond the scope of this analysis. The other popular field is Open Data (six activities).

However, as with the open nature of many of these activities, case studies often combine topics and participants from multiple fields and backgrounds. Activities such as **Challenge Based Innovation (CBI)**, **Open Innovation Laboratories**, and **Ocean i3** all involve HEI students across science, humanities and art disciplines to work together, and even encourage students to collaborate with stakeholders outside HEI settings. While innovation-focused, activities such as **Challenge Based Innovation (CBI)** and **Open Innovation Laboratories** emphasise service design, especially for addressing Sustainable Development Goals. Open data activities also deal with data from a variety of fields, including public government data (e.g. **A Scuola di OpenCoesione**), environmental data (**Project EDDIE**), social science community data (**Rwanda refugee data program**), and biotracker data (**Alan Walks Wales Dataset**).

Case studies also varied by their elements of openness and their combinations (e.g. open science/research, citizen science, open data, open source software, open source hardware, open innovation, OER and OEP).

*Table 3.1 – Key details of the open science/innovation activity case studies selected. More information of each case study is available in Annex A. Activities are listed by alphabetical order of field, followed by name of case study. *Short projects are completed within a day (including games), long projects take a few days to a few weeks to complete, courses take a month to six months to complete.*

No.	Field	Case study	Location	Activity scale*	Participants
1	Ecology	*BOKUroadkill* by University of Natural Resources and Life Sciences Vienna	Austria	Long project	HEI students
2		*City Nature Challenge* by Natural History Museum Los Angeles County, and California Academy of Sciences; using *iNaturalist* app by California Academy of Sciences and National Geographic	Worldwide (conducted in participating cities worldwide)	Short project	School students, HEI students, general public
2		*Eesti otsib nurmenukke [Estonia is Looking for Primroses]* by Tartu University, Eestimaa Looduse Fond (Estonian Nature Foundation) and Let's Do It! Foundation	Estonia	Short project	School students
3		*Nature's Notebook* by USA National Phenology Network	Worldwide (web-based)	Short project, long project, course	School students, HEI students, general public
4		*Neighborhood Nestwatch* by Smithsonian National Zoo & Conservation Biology Institute	USA	Long project	School students
6		*The National Institute of Invasive Species Science (NIISS) Educational Program* by National Institute of Invasive Species Science	USA	Course	General public
7	Engineering and Design	*Challenge Based Innovation (CBI)* by CERN (European Organisation for Nuclear Research)	Switzerland	Course	HEI students (from business, design and engineering)
8		*Open Innovation Laboratories* by Tecnológico de Monterrey	Mexico	Course	HEI students in collaboration with researchers, industry, government and general public
9	Environment	*air:bit* by UiT The Arctic University of Norway	Norway	Long project	School students (upper secondary)
10		*iSCAPE Living Labs* by iSCAPE Consortium [EU Horizon 2020 Project]	Italy, Germany, Ireland, UK, Belgium, Finland	Long project	General public
11		*Masseeksperiment 2019 [Mass Experiment 2019]* by Astra, and *Det Danske Forskningscenter i Marin Plastforurening 'MarinePlastic'* (The Danish Research Center in Marine Plastic Pollution)	Denmark	Long project	School students

No.	Field	Case study	Location	Activity scale*	Participants
12	Environment	*Ocean i3* by University of Bordeaux, and University of the Basque Country	Spain and France	Course	HEI students (from multiple disciplines)
13		*Waterwatch/Saltwatch/ Estuaryrwatch programs* by Waterwatch Victoria	Australia	Long project	School students
14	General science	*National Geographic Education* by National Geographic	Worldwide (web-based)	Short project	School students, school teachers
15		*nQuire* by The Open University and BBC (formerly nQuire-it)	Worldwide (web-based)	Short project	General public
16		*Open Science School* by Open Science School (France)	Worldwide (web-based)	Course	School students (high school)
17		*OpenSciEd* by OpenSciEd Consortium	Worldwide (web-based), content tailored to USA curriculum	Course	School students (middle school)
18		*Science at Home's Quantum Moves* by Aarhus University (Denmark)	Worldwide (web-based)	Short project (game)	School students, HEI students, general public
19	Open Data	*A Scuola di OpenCoesione* by OpenCoesione [Open Government initiative by Italian government]	Italy	Long project	School students (high school)
20		*Alan Walks Wales Dataset* by University of Birmingham and University of Konstanz	UK	Short project	HEI students
21		*ODEdu: Open Data Education* by ODEdu Consortium [Erasmus+ Project]	Belgium, Denmark, Greece, UK, Malta	Course	HEI students
22		*Open Data School Russia* by Open Data School Russia	Russia	Course	General public
23		*Project EDDIE: Environmental Data-Driven Inquiry and Exploration* by Project EDDIE Team	Worldwide	Short project	HEI students
24		*Rwanda refugee data program* by Pennsylvania State University and UNHCR	Rwanda	Course	Refugees

3.2 Activities for developing open collaboration in science and innovation

3.2.1 Case studies

Section 3.2 refers to the following case studies, which are initiatives that aim to develop and facilitate open collaboration in science and innovation.

1. Challenge Based Innovation @IdeaSquare CERN ("CBI CERN")
2. National Geographic Education
3. nQuire
4. Ocean i3
5. Open Innovation Laboratory @*Tecnológico de Monterrey* ("Open ILab")
6. Open Science School, Paris
7. OpenSciEd
8. Science at Home's Quantum Moves

Due to having different learning goals, citizen science activities for inquiry learning are separately analysed in Section 3.3. Open data activities are also not included, and are explored in Section 3.4.

Several activity types are represented in this selection of case studies. **CBI CERN**, **Ocean i3**, **Open ILab**, and **Open Science School's** Co-Lab workshops are open innovation labs. **nQuire** and **Science at Home's Quantum Moves** are online-based citizen inquiry/science initiatives. **National Geographic Education**, **Open Science School**, and **OpenSciEd** offer curated OER.

Each activity contains different elements of openness, including open science (e.g. the sharing of CERN expert knowledge and facilities with students), citizen science (e.g. the participation of citizens in scientific research), open source hardware (e.g. for data collection equipment), OER (e.g. online courses or freely available lesson plans), OEP (e.g. learning co-design), and open innovation (e.g. cross-disciplinary and multi-stakeholder collaboration).

3.2.2 Learning design

3.2.2.1 Learning goals

The learning goals indicated by each case study are provided in Table 3.2. Within these case studies, there are common learning goals, which can be summarized as:

1. To develop collaboration skills (interdisciplinary, cross-sectoral, intercultural) for problem solving and innovation.
2. To develop sustained and empowered citizen participation in learning and science.

It is interesting to observe that a primary learning goal of these activities is to further develop the open skills of learners. In particular, collaboration skills are emphasised in many of the case studies, including **CBI CERN**, **National Geographic Education**, **Ocean i3**, **Open ILab**, and **Open Science School**. Collaboration, science advancement and innovation are intrinsically linked because there is a growing understanding that collaboration (across disciplines, sectors and cultures) is necessary for the development of innovative science and technology to solve contemporary complex sustainability issues (Charosky et al., 2018; Miranda et al., 2019; National Geographic, 2019d; Open Science School, n.d.-a).

Another common learning goal is to develop sustained and empowered citizen participation in learning and science. Case studies such as **National Geographic Education**, **nQuire**, **OpenSciEd**, **Open Science School** and **Science at Home's Quantum Moves** share this learning goal. These activities aim to develop life-long motivation for learning and/or to empower citizen participation in science.

Table 3.2 – Example learning goals indicated from activities for developing open collaboration in science and innovation.

Case study	Learning goals
CBI CERN	*"One of the major learning goals of the CBI course was for the students to become familiar and confident in the process of creative product development leading to new ideas and front-end innovation – important skills in the field of engineering design"* (Jensen, Utriainen, & Steinert, 2018, p. 41). *"Not all engineering students are prone to become entrepreneurs. The goal is to identify these who are through the exposition to CBI-like experiences and provide them experiences to enhance the innovation and entrepreneurial skills"* (Charosky et al., 2018, p. 452) As described by Hassi et al. (2016, p. 9): • Develop skills applying design thinking tools and methods and product design in a practical, real world project. • Develop skills in moving ideas into testable, tangible prototypes quickly. • Develop skills in interdisciplinary teamwork and communication.
National Geographic Education	"*Key 21st century skills are integral to the National Geographic Learning Framework, which encourages students to explore their world using observation, communication, collaboration, and problem-solving skills*" (Turner, n.d.) Key Attitudes, Skills and Knowledge of National Geographic Kids, as inspired by the characteristics of an explorer (National Geographic, 2019d): • Attitudes: curious, responsible, empowered • Skills: observation, communication, collaboration and problem solving • Knowledge: The Human Journey, Our Changing Planet, Wildlife and Wild Places
nQuire	Citizen inquiry "*engages members of the public alongside scientists in setting up, running, managing or contributing to citizen science projects with a main aim of learning about the scientific method through doing science by interaction with others*" (Herodotou, Aristeidou, Sharples, & Scanlon, 2018).
Ocean i3	*"It is an educational innovation project that seeks to develop transversal competences of university students based on Research Based Learning methodologies and challenges oriented to the 2030 Sustainable Development Goals (RBL-ODS) … The competences being developed, amongst others, have to do with interdisciplinarity, cross-sectoral approaches, systemic and integrated focus of problems, integration of ODS values as well as skills to be able to manage intercultural and multilingual situations"* (Euskampus, 2019).

Case study	Learning goals
Open ILab	This Open Innovation Laboratory promotes the development of 5 core competencies known as the "5Cs": • Critical thinking • Collaboration • Cooperation¨ • Communication • Creativity and innovation (Miranda et al., 2019; Tecnológico de Monterrey, 2019)
Open Science School	*"OSS aims at testing and developing new models for research, long-life learning, and innovation… OSS advocates for a change of policy in existing educational and research institutions, to shift towards a more open model to create and share innovation. OSS develops long-life learning curricula and spaces that encourage people from different backgrounds to collaborate and co-create, taking advantage of their diversity. We acknowledge that the problems science aims at resolving are beyond the reach of scientists alone, and realize that science is embedded in a culture that we need to consider when defining scientific facts and creating new knowledge or innovations. To summarize: "Open Science School aims at changing the way we learn using non-conventional approaches"* (Open Science School, n.d.-b).
OpenSciEd	*"The goal of a science storyline approach is to provide students with a coherent experience that is motivated by the students' own desire to explain something they don't understand or to solve a problem… OpenSciEd storylines are designed to provide students with the goal of explaining a phenomenon and/or solving a problem"* (OpenSciEd, 2019)
Science at Home's Quantum Moves	*"To include students in cutting-edge quantum mechanics research as well as to support learning and motivation for learning"* (Bjælde, Pedersen, & Sherson, 2014, p. 218).

3.2.2.2 Learning objectives and implementation

This section describes the learning objectives, approaches and tasks used to achieve the aforementioned learning goals. The learning approaches and objectives of each case study is described in Table 3.3.

Learning goal 1: To develop collaboration skills (interdisciplinary, cross-sectoral, intercultural) for problem solving and innovation

To develop collaboration skills, a project-based learning approach is often utilised (e.g. **CBI CERN**, **Open ILab**, **Ocean i3**, and **Open Science School's** Co-Lab workshops). **CBI CERN**, which is a three to six weeks course, uses challenge-based education. Learning tasks are framed by the Learning Design process (condensed into three stages as Discover, Design and Deliver; Charosky et al., 2018). In the Discover stage, multidisciplinary teams of university students use research to define a complex, social challenge they wish to problem solve. Examples of past challenges include: "How could technology help to improve the living conditions of refugees, displaced and other people in need of emergency temporary sheltering?" and "How to use new technologies to revamp radiation inspection methods?". In the Design stage, students generate multiple ideas and solutions and develop low-resolution prototypes (e.g. cardboard, paper) to conduct user testing and design iteration. At the end of this stage, one solution is selected to be developed with higher resolution (e.g. 3D printing). In the Deliver stage, the selected solution is prototyped to proof of concept level and is presented in a gala event in CERN, to an audience of scientists, universities, and media (Charosky et al., 2018).

Open ILab's sixteen-week Design Methodologies university course has a similar approach, where multidisciplinary groups of students also follow a design process (i.e. ideation, conceptual design and specification, detailed design and prototyping) to develop a new product that responds to current social issues (Miranda et al., 2017). Open ILab integrates problem-based learning, case-based learning, project-oriented learning, service learning and challenge-based learning (Miranda et al., 2017).

Ocean i3, in addition to research-based learning, also developed open collaboration skills through workshops. For instance, in one workshop, students created a posters on cross-cultural communication (Euskampus, 2019).

In all cases, the multidisciplinarity of team members is emphasised. CBI CERN student project groups are purposely composed of university students of different disciplines (engineering, business and design) and cultures (Charosky et al., 2018; Hassi et al., 2016; Jensen et al., 2018). In Ocean i3, participation was open to any student regardless of background, attracting students from nursing, health, law, pedagogy, engineering, business studies, and criminology disciplines (Euskampus, 2019). Open ILab encourages university students to collaborate on projects with researchers, industry, government and general public. Open Science School's Co-Lab workshops emphasises horizontal collaboration between participants and mentors, diversity of participants, and an interdisciplinary approach (i.e. integrating knowledge and methodologies of multiple disciplines; Open Science School, n.d.-a). Even at younger school settings, the National Geographic Learning Framework emphasises teamwork in its activities to develop collaboration skills (National Geographic, 2019d).

Table 3.3 – Example learning objectives of activities for developing open collaboration in science and innovation.

Case study	Learning approach	Learning objectives
CBI CERN	Challenge-based education and design thinking (Charosky et al., 2018; Hassi et al., 2016)	From CBI Student Guidelines document (Charosky et al., 2018): • *Develop an Advanced Design project applying a methodology focused in product innovation* • *Study and guide the creation of future scenarios, based on a deep analysis of present and past, with the aim of creating new ideas applicable to the new context* • *Analyze the project considering market, society and technology, to define clear areas for new opportunities.* • *Achieve the proper presentation tools to present and explain the design process, both orally and in digital format.* • *Apply a strategy, making decisions for achieving innovation and quality.* • *Fundament the concepts in a multidisciplinary project from a theoretical and practical perspective* • *Present and represent design ideas applying the proper techniques* • *Apply the proper digital technology for the communication and presentation of projects* • *Implement specific design research and experimentation techniques* • *Find out and study the productive processes for the fabrication of the designed projects*
National Geographic Education	National Geographic Learning Framework (which aligns with inquiry-based learning; Oberle, Bess, Ehmke, Rath, & Robbins, 2019) • Many activities use a learning-for-use teaching approach (National Geographic, 2019c) • Service learning is also recommended (National Geographic, 2016)	Example learning objectives from the lesson Making a Decision about Building a Road in the Amazon", which uses the learning-for-use approach (National Geographic, 2019b): • *Identify the role that stakeholders play in determining the outcome of building a road within the Amazon rain forest* • *Identify various geographic and political factors that may influence the decision to build a road in the Amazon rain forest* • *Analyze various consequences from a decision and determine their impact on stakeholders* • *Analyze the role that stakeholders play in determining the outcome of a complex decision* • *Explain the complex nature of environmental issues and recognize the solutions to these issues are usually multi-layered and complex* • *Assess and summarize the impact that a decision had on the stakeholders within the case study*

Case study	Learning approach	Learning objectives
nQuire	Citizen inquiry – an approach that blends inquiry-based learning with citizen science "*nQuire-it combines the pedagogies of inquiry-led learning and learning as conversation*" (Sharples, Aristeidou, Herodotou, McLeod, & Scanlon, 2019)	Example unavailable
Open ILab	*"When the Open Innovation Laboratory is used for educational purposes, the learning process is carried out using two methods, the Active Learning Method and the Blended Learning Method… The main techniques used in Active Learning for this particular work are Problem-Based Learning (PBL), Case-Based Learning (CBL), Project Oriented Learning (POL), Service Learning (SL), Challenge-Based Learning, and Online learning using MOOCs"* (Miranda et al., 2017, p. 1237).	Example unavailable
Open Science School	Research-based pedagogy (Open Science School, n.d.-b)	Example unavailable
OpenSciEd	OpenSciEd units are based on the idea of a science storyline (Reiser, Novak, & Mcgill, 2017), combining phenomena-based teaching and the importance of coherence (OpenSciEd, n.d.)	Details on learning objectives for each learning unit is available at: https://www.openscied.org/access-the-materials/
Science at Home Quantum Moves	Game-based pedagogy (Lieberoth, Pedersen, & Sherson, 2015)	Example unavailable

Learning goal 2: To develop sustained and empowered citizen participation in science learning and research

Several learning approaches are used to foster engagement and interest in science and innovation. In the cases of **National Geographic Education**, **Open Science School**, and **OpenSciEd**, there is a lot of emphasis on getting students motivated to learn by making the content relevant to the self and applicable in the real-world (i.e. useful).

Following the National Geographic Learning Framework, many **National Geographic Education** lesson plans use a learning-for-use teaching approach (National Geographic, 2019c). Learning-for-use is a learning process that results in useful knowledge, which is developed through three steps described in Table 3.4. Learning-for-use bears resemblance with inquiry-based learning – however, while inquiry-based learning aims to engage students with the scientific method of inquiry, the learning-for-use design framework aims to motivate learners based on knowledge usefulness and to instil a need to develop knowledge that is organised to support future access and application (Edelson, 2001).

Table 3.4 – Overview of the Learning-for-Use Design Framework by Edelson (2001), which is used as a learning approach in many National Geographic Education lesson plans.

Step	Design strategy	Student experience
Motivate	Activities *create a demand* for knowledge when they require that learners apply that knowledge to complete them successfully.	Perceive need for understanding
	Activities can *elicit curiosity* by revealing a problematic gap or limitation in a learner's understanding.	Experience curiosity
Construct	Activities that provide learners with *direct experience* of novel phenomena can enable them to *observe* relationships that they encode in new knowledge structures.	Experience or observe phenomena
	Activities in which learners receive direct or indirect *communication* from others allow them to build new knowledge structures based on that communication.	Hear, view, or read about phenomena
Refine	Activities that enable learners to *apply* their knowledge in meaningful ways help to reinforce and reorganize understanding so that it is useful.	Apply understanding
	Activities that provide opportunities for learners to retrospectively *reflect* upon their knowledge and experiences retrospectively, provide the opportunity to reorganize and reindex their knowledge.	Reflect upon experiences or understanding

An example of a learning-for-use lesson by **National Geographic Education** is "Making a Decision about Building a Road in the Amazon", in which the steps of learning-for-use are enacted across three activities (National Geographic, 2019b). In the first activity, students are asked to consider examples of construction projects they have personally observed, and to think of the social and environmental effects. There is a lot of emphasis on making the issue relatable to the students' lives. Students are then given information on the Amazon Road Building case study, asked to brainstorm stakeholders of the project, and then asked to roleplay a discussion between these stakeholders. Students then have to reflect on the Amazon road decision. The opinions of each stakeholder are then organised into a Stakeholder Table worksheet. In the second activity, students discuss the influence of different stakeholders in the decision, identify the various consequences of the decision, and visually illustrate the consequences in a Consequence Web. Students are then allowed to use the web to research and learn more on particular stakeholders they are interested in, and to modify their Consequence Web if needed. In Activity 3, students are asked to revisit what they have learnt in Activities 1 and 2 with the help of their Stakeholder Table and Consequence Web. Then, students create a final decision statement considering all stakeholder perspectives, and are asked to reflect on the decision-making process.

National Geographic Education also recommends the use of service learning to motivate learners to continue learning. Service learning, which combines community service and active learning, provides an authentic experience where students can both learn and apply their learning in real community service projects (National Geographic, 2016). This form of learning has been shown to increase academic engagement, performance, educational aspirations, acquisition of 21st Century skills, community engagement, and social and personal skills (Theriot, 2009). Examples of service learning activities include calculating daily water use at school, growing a school garden makerspace, or taking part in local citizen science projects such as bioblitzes (National Geographic, 2019e, 2019a).

As part of their institutional values, **Open Science School** aims to develop intrinsic motivation through its research-based pedagogy. As stated by Open Science School, "Intrinsic motivation refers to the behavior that arises from within the individual because it is intrinsically rewarding. The importance of this phenomenon constitutes one of the most essential factors in the process of learning. It has been proved that when teaching relies on student's intrinsic motivation - by answering questions in which they are already interested - learning is more effective, essential and long-term lasting" (Open Science School, n.d.-b). Thus, Open Science School focuses on linking the applications of scientific research to the everyday lives of students, creating deep and essential understanding of scientific principles, and providing students with the tools to apply these principles into their daily lives (Open Science School, n.d.-b).

Similar to the approaches of **National Geographic Education** and **Open Science School**, **OpenSciEd's** instructional model also begins with motivating students via relevance. In the first stage of the instructional model ("Kicking off a Unit with an Experience to Motivate Investigation"), a common experience is established between students to elicit and feed student curiosity on a certain problem. To solve the problem, students use an inquiry process that is framed as a "storyline", so to reinforce the idea that scientific inquiry is a coherent sequence of questions and knowledge gains (OpenSciEd, 2019).

Alternatively, **Science at Home's** Quantum Moves uses a game-based pedagogy strategy to get participants interested and engaged with quantum physics research and knowledge (Lieberoth et al., 2015). As a citizen science initiative, players solving the challenges and puzzles posed by Quantum Moves help real researchers collect data to build a real quantum computer (Lieberoth, Pedersen, Marin, Planke, & Sherson, 2014). From a learning standpoint, participants are able to role-play as scientists and gain authentic experience with an existing scientific project.

nQuire, another online-based citizen science initiative, uses a citizen inquiry approach to create a "sustainable community of inquiry" (Herodotou et al., 2018, p. 19). Typically, in citizen science, members of the general public are recruited by scientists for mass data collection (as further discussed in Section 3.3). However, due to their limited participation in the entire scientific inquiry process, participants do not fully learn how to independently lead an inquiry-led scientific investigation. In response, citizen inquiry "extends the practices of citizen science to include investigations that are initiated, planned, designed, executed, analyzed and presented by members of the public" (Sharples et al., 2019, p. 2). In doing so, citizens are empowered to carry on learning and conducting their own science. The nQuire online open platform offers citizen a scaffolding mechanism for citizens to conduct their own personally meaningful and authentic investigations, as well as contribute to other investigations on the platform – thus combining inquiry-based learning and learning as conversation (Aristeidou, Scanlon, & Sharples, 2017; Sharples et al., 2019). When designing and carrying out their own investigations (i.e. learning by doing), participants are guided by an inquiry cycle framework: "find my topic", "decide my inquiry question or hypothesis", "plan my methods, equipment and evidence", "collect my evidence", "analyse and represent my evidence", "respond to my question or hypothesis", "share and discuss my inquiry" and "effect on my progress" (Aristeidou et al., 2017; Herodotou et al., 2018). As an open platform, nQuire also engages citizens and scientists to openly collaborate (Herodotou et al., 2018).

3.2.2.3 Tools and resources

In many case studies, a space is given for collaboration. This may be a physical space, such as for **CBI CERN**, **Open ILab** and **Ocean i3**. Within these spaces, facilities are made available for students to ideate, prototype, test and present their products of their collaborations. These facilities include technologies for prototyping (e.g. makerspaces, fab labs, virtual reality platforms) and areas for discussions (CERN, n.d.; Euskampus, 2019; Miranda et al., 2019). In addition to sharing facilities, **CBI CERN** also provided participants with mentors to better acquaint students with available CERN expertise and resources (Charosky et al., 2018). In the case of **nQuire**, the collaboration space is virtual via its online platform (Sharples et al., 2019).

National Geographic Education, Open Science School and OpenSciEd offer OER (e.g. lesson plans, classroom posters, infographics, worksheets, sample presentations) to educators via their websites.

Open Science School, with the intention to make an open source, low cost lab tool, developed the Open Hardware Spectrophotometer for use in biochemistry and environmental science experiments (Open Science School, n.d.-c).

3.2.3 Learner responses

Learning goal 1: To develop collaboration skills (interdisciplinary, cross-sectoral, intercultural) for problem solving and innovation

Information on learner responses are available for **CBI CERN**, from Charosky et al. (2018) and Jensen et al. (2018). Charosky et al. (2018) reports on the learner responses across four iterations of CBI CERN programs co-created with ESADE Business School, IED Instituto Europeo di Deisgn, and the Telecom Engineering School of UPC, Universitat Politècnica de Catalunya. Charosky et al. (2018) compares the learner responses of engineering students participating in the CBI CERN program with those participating in the “standard” course in the Telecom Engineering School. Feedback from Charosky et al. (2018) was gathered via a specific feedback session with all students and faculty members, an individual reflection document and several questionnaires supplied by different institutions.

Jensen et al. (2018) reports on a separate CBI CERN program that included seven universities from Australia, Finland, Italy, Norway and Spain conducted from September 2014 to February 2015. Jensen et al. (2018) investigated the learning barriers introduced by multidisciplinarity and remote participation (participants met at CERN, at their respective countries, and online in order to collaborate). Feedback from Jensen et al. (2018) was obtained through questionnaire answers of 37 participants of the program.

Learner responses for both CBI CERN programs are summarised in Table 3.5. From the feedback, at least in the case of **CBI CERN**, it is evident that the learning goal (to develop collaboration skills for problem solving and innovation) can be achieved.

Table 3.5 – Example learner responses from two separate CBI CERN programs.

	Strengths	Challenges
CBI CERN by Charosky et al. (2018)	• The true multidisciplinary structure of teams is the most valuable aspect of the course. • International experience • Interaction with high-level scientists and technologies at CERN • The inclusion of intensive periods in singular workspaces, out of the regular classrooms and labs has also been identified as a key factor for success. • The Design Thinking approach provides powerful tools and a systematic way to deal with uncertainty in open challenges. • This multidisciplinary experience has been shown to be a successful tool to enhance innovation and entrepreneurial skills in engineering students.	• Due to its cost, the program cannot be scaled to all the students, but the methods and lessons learnt can be applied to standard courses at the home institutions. • A tradeoff: the direct contact with users improves creative design part (i.e. needfinding and ideation), but reduces time for designing complex solutions and the associated learner responses. With limited time and resources, engineering students should choose between acquiring more entrepreneurial skills or more technical skills.
CBI CERN by Jensen et al. (2018)	• Paper focused on learning challenges to support interdisciplinary educational setups.	• Remote collaboration creates challenges for students to work together (e.g. time difference and basic infrastructure). • The difficulty of initial phases of engineering design process influenced the experienced difficulty in the final stages of the project. The study highlights the importance of a facilitator during and in between design phases. • When participants were remotely located, collaboration was difficult, especially between those of different backgrounds. • Team dynamics was more important than professional background in determining project difficulty. Teaching teamwork and communication skills may decrease disciplinary egocentrism and increase the potential of multidisciplinary teams.

Learning goal 2: To develop sustained and empowered citizen participation in science learning and research

Information on learner responses are available for **nQuire**. Herodotou et al. (2018) presents a set of interaction design principles produced from four years of iterative pedagogy-led design, as well as evaluation of 240 end users, a group of eight experts in technology-enhanced pedagogy and user experience, and seven structured interviews with citizen science volunteers. Villasclaras Fernandez, Sharples, Kelley, & Scanlon (2013) is an evaluation of a citizen inquiry project developed with the help of the **nQuire** toolkit, and thus is also able to provide insight on the **nQuire** approach.

Information on learner responses are also available for several versions of **Science at Home's Quantum Moves**. Magnussen, Hansen, Planke, & Sherson (2014) presents the results from testing an educational version of Quantum Moves at three separate high school classes, who were assessed using video observations of students playing the game, qualitative interviews, and qualitative and quantitative questionnaires. Bjælde et al. (2014) presents a small case study of using an early version of Quantum Moves to teach in a quantum mechanics course – 64 students were assessed using a pretest/posttest method. Lieberoth et al. (2014) summarises data about participation for the beta year of Quantum Moves implemented across high schools, university classes, public events and lectures. Lieberoth et al. (2015) reports on the responses of 38 vocational school students, who were surveyed after playing Quantum Dreams (a variation of Quantum Moves) for 15 minutes during a science class.

The learner responses for **nQuire** and **Science at Home's Quantum Moves** are summarised in Table 3.6. From the feedback, it is evident that the learning goal (to develop sustained and empowered citizen participation in learning and science) can be achieved.

Table 3.6 – Example learner responses for nQuire and Science at Home's Quantum Moves.

	Strengths	Challenges
nQuire by Herodotou et al. (2018)	• Young participants revealed satisfaction with using personal mobile devices to run scientific investigations and to collect data. • Users are more likely to use and keep using the website if they see and feel it to contain a vibrant community achieving a purpose.	• One of the major challenges is to create a sustainable community of inquiry. • Platform activity declined rapidly by the end of the project, suggesting that engaging facilitators to monitor the online activity and to scaffold different missions can support participation and sustainability. • It is a challenge to introduce investigatory science to people without prior training in scientific methods. This may be managed by recruiting expert scientists from academia, science organisations, and schools as regular participants on the platform to guide newcomers through the inquiry process.

	Strengths	Challenges
Moon Rock Explorer (developed from the *nQuire Toolkit*, with some differences) by Villasclaras Fernandez et al. (2013)	• Analysis of the participants' work indicates that participants can develop complete inquiries following the inquiry cycle.	• The system did not support the creation of a community-like atmosphere with a lot of user interaction and collaboration. • The most exciting open challenges are related to the issue of motivation. Several mechanisms are under consideration to foster motivation in collaborative inquiries: reputation systems, support for roles within large scale inquiries (similar to citizen science projects), and an internal peer-reviewed 'scientific journal' for members of the citizen inquiry community.
Quantum Moves at high schools by Magnussen et al. (2014)	• Participating in an authentic scientific experiment is highly motivating for students. Students responded well to research collaboration or solving real physics problems. In response, organisers strengthened the authentic aspects of the game by making the researchers more visible on the game's website with profile photos and adjusting the game graphics to better match the atmosphere of the actual physics lab. • Scores was also a motivating factor. • The game and setup in the class thus provided a strong experience of participating in an authentic experiment, but less evident experience of learning physics from the participation. • The game offered a more intuitive approach to visualise a highly theoretical physics concept, which encouraged weaker students to participate more actively.	• None mentioned
Quantum Moves by Bjælde et al. (2014)	• On average. students gained up to 20% on posttest compared to pretest scores on quantum mechanics when exposed to a teaching session with gameplay. • Students who scored low on the pretest had a significant gain from the gameplay sessions. Students with high grades learn more than the average students.	• Students who responded to have had fun during the gameplay sessions actually performed significantly worse than the average student. It seems to indicate that some students get too focused on playing the game, thus hindering their learning.

	Strengths	Challenges
Quantum Moves by Lieberoth et al. (2014)	• Our data comparing those forced to play via schoolwork to players who came to us via in-world events or online channels also suggest that users are much more inclined to play if the action springs from curiosity or if players are intrinsically motivated to contribute to science.	• The high level of cognitive complexity in Quantum Moves compared to citizen science games that rely on players as simple pattern-hunters or "mules" carrying data gathering devices into the real world, means that we will lose players at a higher rate due to the difficulty, but we believe that it is a viable strategy to work towards a game that is fun and learnable for everyone
Quantum Dreams for Lieberoth et al. (2015)	• The game supplies a first-hand experience with the behaviour of atoms in quantum space, which is very hard to grasp even for trained scientists. • Participants described their experience using a combination of "game", "science" and "conceptual" frames of understanding, suggesting that oscillating between frames instead of focusing on one led to largest number of correct science interpretations, as players could participate legitimately and autonomously at multiple levels of understanding.	• Game thinking may be distracting, as students may focus on game aspects, rather than on the scientific explanations.

3.3 Citizen science activities for inquiry learning

3.3.1 Case studies

Section 3.3 focuses on citizen science activities that are used for inquiry-based learning. These activities, listed below, are distinct from the other case studies because their learning goals focus on teaching specific scientific content, raising awareness on a certain cause, and/or improving understanding of the scientific inquiry method. Inquiry-based learning is also heavily emphasised in these activities.

1. BOKUroadkill
2. City Nature Challenge
3. *Eesti otsib nurmenukke* (“Estonia is Looking for Primroses”)
4. Nature’s Notebook
5. Neighborhood Nestwatch
6. The National Institute of Invasive Species Science (NIISS) Educational Program
7. air:bit
8. iSCAPE Living Labs
9. *Masseeksperiment* 2019 (“Masseeksperiment”)
10. Waterwatch/Saltwatch/Estuarywatch programs by Waterwatch Victoria (“Waterwatch”)

Unintentionally, all of these case studies were of the Environment and Ecology fields, which is simply a reflection of the popularity of these forms of citizen science activities. All of the Ecology case studies were concerned with species observation and monitoring. Participants recorded and gathered information on urban biodiversity (**City Nature Challenge/iNaturalist**), primroses (**Estonia is Looking for Primroses**) plant/animal phenologies (**Nature’s Notebook**), bird species (**Neighborhood Nestwatch**), roadkill (**BOKUroadkill**), and invasive species (**NIISS Educational Program**). Monitoring is also prevalent in the Environment case studies, of which most involve environment/pollution monitoring. Participants recorded and gathered information on air quality (**air:bit** and **iSCAPE**), plastic pollution (**Masseeksperiment**) and water quality (**Waterwatch**).

The emphasis on monitoring within Ecology/Environment is reflective of the overall pattern of open/citizen science activities in these fields. As Ecology/Environment research often requires considerable fieldwork, a popular action for researchers is to crowdsource data collection through citizen science initiatives (Pocock, Chapman, Sheppard, & Roy, 2014). For instance, in the **City Nature Challenge**, species monitoring data were uploaded by citizen scientists into the iNaturalist app, from which datasets were published and shared with scientists (Horn et al., 2018; iNaturalist, 2019; Michonneau & Paulay, 2015).

These activities contain elements of open science (in the form of citizens participating in data collection and study design, i.e. citizen science), open data (data collected is commonly made accessible to the public), open source software (for data collection equipment), open source hardware (for data collection equipment), and OER (open access to resources to supplement educational value of activities).

3.3.2 Learning design

3.3.2.1 Learning goals

Learning goals of each case study is presented in Table 3.7. The learning goals were generally of two categories:

1. To improve knowledge on a certain topic (including cause awareness and appreciation).

2. To improve understanding of the scientific method.

These two learning goals correspond with the general impression of citizen science activities beyond our selected case studies (Bonney et al., 2009; Cronin & Messemer, 2013; Cronje, Rohlinger, Crall, & Newman, 2011; Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011; Kobori et al., 2016; Martin, 2017; Pandya & Dibner, 2019; Riesch & Potter, 2014; Wiggins & Crowston, 2011).

Table 3.7 – Example learning goals of citizen science activities for inquiry learning.

Case study	Learning goals
City Nature Challenge	"*The first City Nature Challenge was an eight-day competition between Los Angeles and San Francisco, engaging residents and visitors in documenting nature to better understand urban biodiversity*" (City Nature Challenge, 2019).
iSCAPE Living Labs	"*ISCAPE Living Labs study, test and implement design and technology interventions to improve the air quality of our cities… ISCAPE Living Labs are not only a technology-driven endeavour, but they are also aimed at directly involving citizens and city stakeholders and promoting behavioural change*" (iSCAPE, 2016).
Nature's Notebook	"*Nature's Notebook is an off-the-shelf program that can readily be folded into university curricula. Additionally, many phenological stages are relatively simple to observe and record, making observing phenology an ideal way to engage students and enhance climate change education efforts*" (Posthumus & Crimmins, 2011, p. 186)
Neighborhood Nestwatch	*"The Neighborhood Nestwatch (NN) program engages citizen scientists in the collection of scientific data and fosters scientific literacy and increased attachment to place in their local natural environment* [to increase conservation awareness]" (Evans et al., 2005, p. 589).
BOKUroadkill	"*Students' feedback statements indicated that we indeed reached our education goals: The students expressed the feeling that they learned scientific working in an applied way – from defining a hypothesis, to gathering data, analyzing data, making graphs and interpreting the findings. The project increased their roadkill awareness when gathering data and thinking about the findings. In addition, participants found that over the course of participating in this project, they became more sensitized to wildlife and conservation issues and will more likely share this awareness with others*" (Heigl & Zaller, 2014, p. 171).
Waterwatch	*"Through the Waterwatch Program, citizen scientists are supported and encouraged to become actively involved in local waterway monitoring and onground activities"* (Waterwatch Victoria, 2019).

3.3.2.2 Learning objectives and implementation

While these citizen science initiatives offer educational activities, for most, the educational components are not "required" for participation, since many citizen science activities have been developed primarily for research (Phillips, Ballard, Lewenstein, & Bonney, 2019; Villasclaras Fernandez et al., 2013). Nevertheless, there is a high potential for inquiry-based learning because participants are directly involved in the scientific process (Fee, 2015; Phillips et al., 2019; White & Frederiksen, 1998). As a result, citizen science activities are often categorised as a form of informal science learning (Bonney et al., 2014; Crall et al., 2012; Phillips et al., 2019).

Supplementary educational activities may be offered to add educational value of the citizen science activities. Often, this extra teaching responsibility is "delegated" to others (e.g. **City Nature Challenge**, **Estonia is Looking for Primroses**, **Nature's Notebook**, **air:bit**, **Masseeksperiment**, **Waterwatch**) and OER are offered to external educators, typically school teachers.

Thus, citizen science activities are often promoted as an opportunity to integrate authentic, inquiry-based learning into lessons and curricula (Crall et al., 2012). With **City Nature Challenge**, external educators are provided access to resources explaining how to implement inquiry-based learning via citizen science into their lessons (City Nature Challenge, n.d.), such as the *Investigating Evidence* teacher's guide by the Cornell Lab of Ornithology (Fee, 2015). Similarly, **Masseeksperiment** promotes the use of the *Engineering i skolen* (Engineering in the School) learning model in combination with its citizen science activity (Astra, 2019). *Engineering i skolen* is inspired by how engineers work and combines problem-based and process-oriented learning (Auener, Daugbjerg, Nielsen, & Sillasen, 2018).

The potential of citizen science for inquiry-based learning is also evident with **Nature's Notebook,** which describes itself to offer "place-based, hands-on learning opportunities" (Posthumus & Crimmins, 2011; USA National Phenology Network, 2019). The University of Minnesota, under its Driven to Discover project that aims to "enable authentic inquiry through citizen science", designed a curriculum guide to teach phenology using **Nature's Notebook**. In a science education course at Salem State University, **Nature's Notebook** is also used to demonstrate to education students that citizen science is useful to integrate inquiry, hands-on discovery and project-based learning into elementary school curricula (Department of Childhood Education and Care, 2015).

According to Pedaste et al. (2015), inquiry-based learning activities generally consist of the following phases: 1) orientation, 2) conceptualisation, 3) investigation (including data collection and data interpretation), 4) conclusion, and 5) discussion. To borrow these terms, the citizen science activity itself (i.e. the data collection) is essentially the investigation phase. Supplementary learning activities typically address the pre- and post-data collection phases to complete the inquiry process.

Citizen science activities with more established pedagogical considerations include **BOKUroadkill**, which was designed as a project within a university course (Heigl & Zaller, 2014), the **NIISS Educational Program**, which was developed with an educational purpose (Crall et al., 2012), and **iSCAPE Living Labs**, which is designed to be a self-sustaining public citizen science initiative. All are driven by inquiry-based learning.

Citizen science can also be used for place-based learning. **Neighborhood Nestwatch** argues that place-based learning resulting from fieldwork increases participants' attachment to their local natural environment, thereby increasing awareness and interest in local conservation initiatives (Evans et al., 2005).

As previously mentioned, inquiry-based learning activities consist of: 1) orientation, 2) conceptualisation, 3) investigation (including data collection and data interpretation), 4) conclusion, and 5) discussion (Pedaste et al., 2015). Borrowing these terms, learning tasks in citizen science initiatives typically address the pre- and post-data collection phases to complete the loop of inquiry (condensed into three general phases below; also see Figure 3.1). With each phase, there are different learning objectives and implementation methods.

1. **Orientation and conceptualisation:**

   Before data collection, participants can learn more information of the research project and the data they are about to collect. Generally, the learning objective is for the participants to be orientated with the topic/issue and understand the scientists' conceptualisation of the project. For example, in each Ecology case study, participants were trained to identify animal and plant species and to understand why species data is important (City Nature Challenge, n.d.; Crall et al., 2012; Eestimaa Looduse Fond, 2019; Evans et al., 2005; Heigl & Zaller, 2014; Posthumus & Crimmins, 2011; USA-NPN National Coordinating Office, 2013). In the Environment case studies, participants were similarly trained to understand why environmental data is needed.

These learning objectives, to remember and understand, were achieved via instruction (e.g. presentations, online videos), fieldtrips, worksheets, games and experiments. Before participants are able to collect data in the field, the **NIISS Education Program** first conducted an eight-hour "indoor training" that included lessons in invasive species, scientific equipment, sampling design, vegetation monitoring protocols, and use of the website for data entry (Crall et al., 2012). Prior to the **BOKUroadkill** project, students attended a lecture, a laboratory exercise, and a field excursion to gain the theoretical background on animal biology and ecology and to learn about animal identification and ecosystems. **Masseeksperiment** students can learn polymer identification via provided online videos and worksheets (Astra, 2019). **Waterwatch** offers a board game to help school students learn about river health, the impacts on unhealthy rivers and the measures to improve the health of rivers (Waterwatch Victoria, n.d.). Students may also conduct scientific experiments to reinforce ideas relevant ideas to the topic. With **Waterwatch**, students also used experimentation to learn the effect of salinity on water density, an important knowledge point for water quality assessment (Bolus, Herben, & Wynn, 2016).

2. Investigation (data collection)

Because citizen science activities produce data for scientific analysis, there are specific data collection procedures. This is important to ensure data quality, so that the data is valid for scientific use (citizen science participants typically carry fieldwork out without expert supervision). Learning objectives in this phase usually involve learning the correct method for data collection (including how to operate equipment), as well as understanding the reason for the methodology. Examples of learning objectives are as follows:

Table 3.8 – Example learning objectives from citizen science activities for inquiry learning.

Case study	Learning objectives
Neighborhood Nestwatch	From Banding Demonstration activity (Smithsonian's National Zoo & Conservation Biology Institute, n.d., p. 1): • Learn how bird banding is used as a tool to monitor and track birds • Learn the difference between aluminum and color bands, and the importance of each • Learn ways they can use color bands to help scientists
Waterwatch	From Waterwatch Monitoring Teacher Resource Pack (NRM Education, 2018, p. 4): • Test water samples for pH levels, turbidity, salinity, and nitrates and phosphates, using scientific equipment • Collect data (and compare to existing data where possible) • Draw conclusions based on collected data

In the **NIISS Educational Program**, participants also had the opportunity to apply their knowledge and adjust the sampling method based on the characteristics of their field site (Crall et al., 2012).

These learning objectives were achieved in the field through participation in data collection. Data collection may be conducted as part of a bioblitz-style event (e.g. **Estonia is Looking for Primroses**,

Masseeksperiment, **City Nature Challenge**), or as a formal educational project (e.g. **BOKUroadkill**, **Waterwatch**, University of Minnesota's curriculum guide for **Nature's Notebook**).

3. Investigation (data analysis), conclusion and discussion

After collecting data, participants may be asked to analyse it. The learning objectives are for participants to apply and transform data to answer a research question. This learning objective was achieved via classroom discussions, report writing, and worksheets.

In the **NIISS Educational Program**, participants had to use the data to discuss and answer research questions such as: *What invasive species are currently coming into a local area? Have efforts to control a species been effective? Is the population of a species growing or shrinking over time? Does the population of a species differ in different habitats?* In **BOKUroadkill**, students developed their own research question and responded to it in a scientific report (Heigl & Zaller, 2014). In the University of Minnesota's **Nature's Notebook** curriculum guide, students are asked to graph data and fill in a worksheet to build a scientific explanation (Thompson et al., 2018).

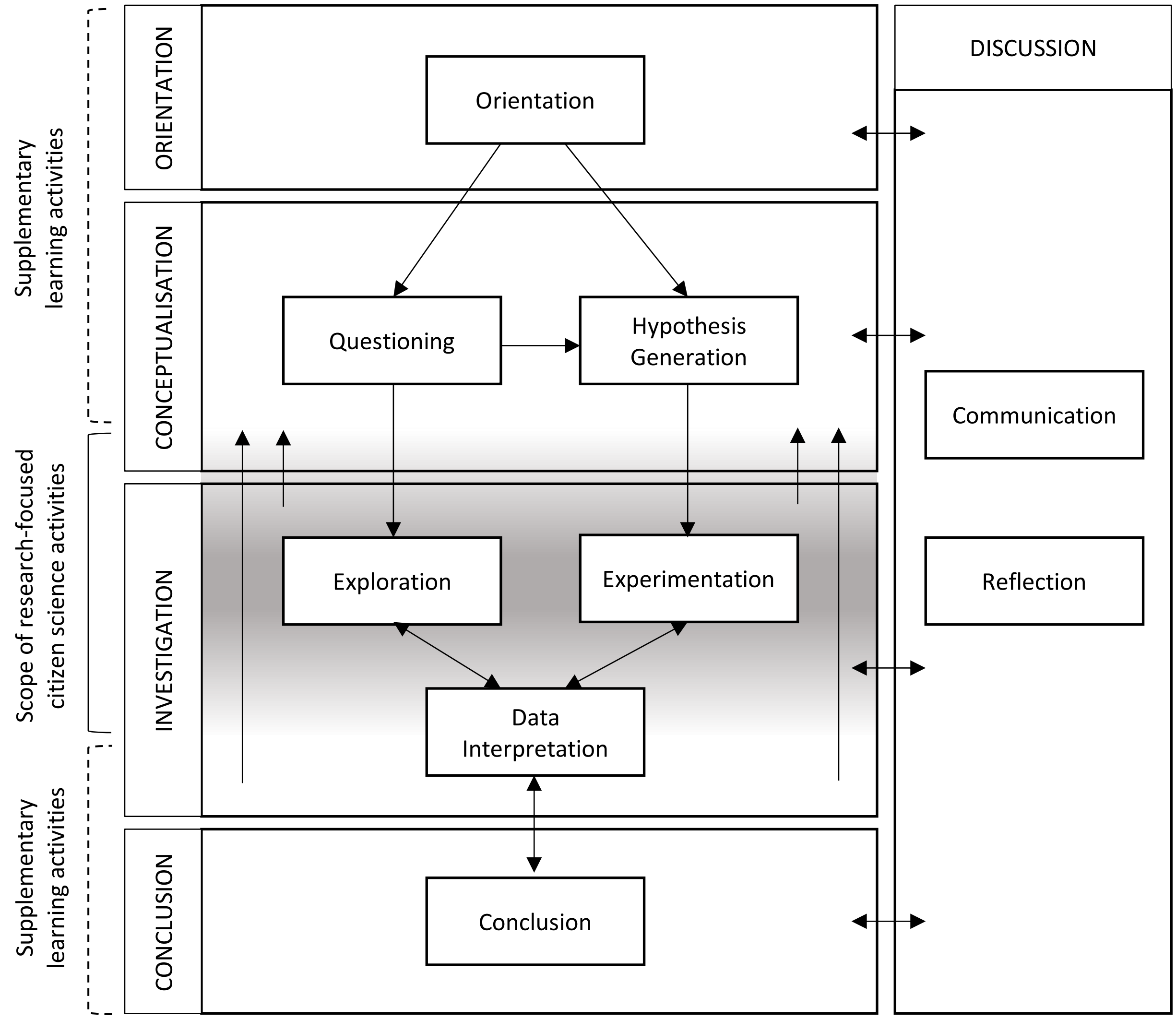

Figure 3.1 – The learning scope of many citizen science activities within the context of the inquiry-based learning framework (framework adapted from Pedaste et al, 2015). In certain citizen science activities, participants are mainly involved in data collection (phase represented by greyed area) and are not involved in other stages of the inquiry process. Citizen science initiatives that aim to enhance participant learning further generally design/carry out supplementary learning activities to address the pre- and post-data collection phases to complete the inquiry-based learning process. Examples of activities are described in Section 3.3.2.2.

3.3.2.3 Tools and resources

With data collection and fieldwork playing a large role in these activities, organisers have prepared accessible methods for participants to record and submit observation data. Participants can do so through their mobile phones or computers, either via an app (e.g. the iNaturalist app for **City Nature Challenge**, and EpiCollect for **BOKUroadkill**), or an online form (e.g. Estonia is Looking for Primroses, Nature's Notebook, Neighborhood Nestwatch, Waterwatch). If there is the lack of internet-access in the field, there is the option of paper forms (downloadable via their website, e.g. **Estonia is Looking for Primroses**), or enabled offline use of their app (e.g. iNaturalist for **City Nature Challenge**).

Specialised scientific equipment may be required for data collection. The **Waterwatch** Water Quality Monitoring Kit provides the necessary equipment to measure electrical conductivity, turbidity, pH, reactive phosphorus, and water/air temperature (NRM Education, 2018). Participants of the **NIISS Educational Program** use Global Positioning Systems units (Crall et al., 2012). Both **iSCAPE** and **air:bit** embrace openness further by developing low-cost, open source air quality sensors. The Smart Citizen Kit by **iSCAPE** is "a flexible, easy-to-use and fully open-source environmental monitoring solution for particulate matter, carbon monoxide, nitrogen dioxide, noise levels, and many other indicators" (Camprodon et al., 2019, p. 1). Similarly, the **air:bit** Sensor Kit is "a programmable sensor kit that students build and program to collect air quality data" with open source building and coding instructions (Fjukstad et al., 2019, 2018, p. 227).

All activities have their own dedicated websites, providing a variety of useful resources for participants and educators. At the most basic level, these websites provide logistical information of the activity (e.g. date and venue), background information on the motivation to collect the type of data, background information on the organisers, and contact information. In addition, websites typically include educational resources. This may be in the form of educational and demonstration videos, articles/blogposts, webinars and podcasts generally targeted towards participants who are interested in learning more scientific information.

In some cases, OER are also provided for educators. Via their websites, activities such as City Nature Challenge, Masseeksperiment, Nature's Notebook and Waterwatch provide resources for school teachers wanting to integrate the citizen science activity into their lessons. These resources take the form of teacher's guides, lesson plans, sample activities and various teaching materials (e.g. classroom posters, infographics, worksheets, sample presentations, downloadable open source board game "Run of the River" by **Waterwatch**). **City Nature Challenge** and **Nature's Notebook** even provide different lesson and activity plans for different age groups and audiences. While most of these resources are self-produced, activities such as **City Nature Challenge** and **Masseeksperiment** also provide external links to videos and lesson plans from other organisations (e.g. OER by National Geographic and the WWF World Nature Fund).

Though not always the case, organisers may provide open access to the datasets collected by participants, via data portals on their websites. For example, on the Nature's Notebook, NIISS Educational Program, air:bit, **Masseeksperiment**, and Waterwatch websites, site visitors are able to view, visualise, select and/or download data. To demonstrate the use of the data, websites also usually feature a list of publications that have resulted from the datasets (e.g. Nature's Notebook, Neighborhood Nestwatch, BOKUroadkill, iSCAPE, Waterwatch).

As with the iSCAPE Living Labs Platform, the website may also serve as a virtual collaboration space for participants.

3.3.3 Learner responses

Since citizen science learning is often informal, and since teaching is not always not conducted by the organisers, there is a general lack of learning assessment available. This is the case for **City Nature Challenge**, **Estonia is Looking for Primroses**, **Nature's Notebook**, **Masseeksperiment**, and **Waterwatch**, as teaching is "delegated" to others, especially school teachers. While supplementary educational activities (i.e. the OER) suggested by the organisers can allow learning assessment, there is typically a lack of a routine, formal learning assessment of the citizen science activity. Results from supplementary educational activities implemented in external classrooms have not been published.

Nevertheless, a few learning assessments have been published. This includes a student feedback survey for **BOKUroadkill** (Heigl & Zaller, 2014) a report on participant surveys and interviews for **Neighborhood Nestwatch** (Evans et al., 2005), and a pretest-posttest survey for the **NIISS Educational Program** (Crall et al., 2012). Longitudinal information was not available, so these results reflect the outcomes of an individual run of each activity. The following table summarises the feedback responses for each of these assessments:

Table 3.9 – Example learner responses from citizen science activities for inquiry learning.

	Strengths	Challenges
BOKUroadkill (Heigl & Zaller, 2014)	• Increased roadkill awareness • A good way to learn scientific working • Offer of an online alternative for non-smartphone users • Using smartphones in education increase learning progress • Increased roadkill awareness among others	• Malfunction of the app (e.g., synchronisation problems, screen freeze) • Road type and road safety limiting scope of data collection • Difficulty in finding roadkill • Laborious online form
Neighborhood Nestwatch (Evans et al., 2005)	• Participants responded very positively to face-to-face interactions with scientists – participants learnt more as a result • 90% of responders reported learning from participation, including learning of new bird species and understanding of bird ecology • Clear examples of scientific thinking that emerged during interviews with participants • Increased awareness of the value of the backyard as a habitat for plants and animals	• Many participants (44%) did not understand the overall goals of the research project, and were not sure how the data would be used
NIISS Educational Program (Crall et al., 2012)	• Content learning gains • An increase in process skills • Participants appear to be more scientifically literate than the general population • Citizen scientists have stronger positive attitudes toward the environment than the general public • An increase in self-reported intention to engage in pro-environmental activities	• None mentioned

From the feedback, despite its limitations, it is possible to see that citizen science activities have the potential to achieve the learning goals: 1) to improve knowledge on a certain topic (including cause awareness and appreciation), and 2) to improve understanding of the scientific method. However, more formal and routine learning assessments of individual citizen science programs are necessary for the development of citizen science as an educational activity (Bonney et al., 2009; Bonney, Phillips, Ballard, & Enck, 2016; Phillips et al., 2019). The lack of information on learner responses from citizen science activities has led to the development of citizen inquiry, an approach that puts more focus on designing for learning (Aristeidou et al., 2017) – citizen inquiry was explored previously in Section 3.2.

3.4 Activities for open data training and innovation

3.4.1 Case studies

This section refers to the following case studies, which are initiatives on open data education:

1. *A Scuola di OpenCoesione*
2. Alan Walks Wales Dataset
3. ODEdu: Open Data Education
4. Open Data School Russia
5. Project EDDIE
6. Rwanda refugee data program

These activities differ from case studies previously discussed because they focus on developing skills and facilitating innovation using open data. Open data activities also deal with data from a variety of fields, including public government data (e.g. **A Scuola di OpenCoesione**, **Open Data School Russia**), environmental data (**Project EDDIE**), social science community data (**Rwanda refugee data program**), and biotracker data (**Alan Walks Wales Dataset**).

These activities contain elements of open science, open data, citizen science, OER (e.g. openly available lesson plans and classroom resources), open software, OEP, and open innovation.

3.4.2 Learning design

3.4.2.1 Learning goals

In general, these open data initiatives were established because there is a greater appreciation for open data and its applications, and thus there is also an increasing demand for open data skills (Schops, 2016). For example, a primary aim of Project EDDIE is to teach university students data analysis and modelling to investigate climate change, using large public datasets (Carey & Gougis, 2017; O'Reilly et al., 2017). "Modelling is a critical tool for environmental scientists because it allows them to study phenomena occurring at spatial and temporal scales for which we do not have observational data, as well as fore- cast the effects of future climate scenarios. Many ecosystem models are computationally intensive and written in scripting languages, so researchers need familiarity with different approaches of importing and exporting large datasets… or network common data form… different programming languages… and different techniques for high-throughput computing… These skills are generally not taught in most ecology undergraduate or graduate classrooms" (Carey & Gougis, 2017, p. 1). These sentiments are applicable to the growing amount of data in other fields as well, including humanities and art fields.

The learning goals for each of the case studies are presented in Table 3.10. Overall, the learning goals between the case studies are very similar and can be summarised as:

1. To increase awareness of open data, to improve skills in open data, and to promote the use of open data.

While having similar learning goals, the contexts of each case study are different. **Open Data School Russia** focuses on general open data literacy for the general public and journalists. **A Scuola di OpenCoesione** promotes the use of government open data for civic monitoring for school students. **ODEdu** focuses on general open data literacy for HEI students. **Project EDDIE** and the **Alan Walks Wales Dataset** provides university students authentic exercises with working with real data. The **Rwanda refugee data program,** aimed to empower refugees with skills in data collection and analysis, using open source technology. The diversity of contexts reflects the global growth of open data and its significance. Cases such as the **Open Data School Russia**, **A Scuola di OpenCoesione**, and the **Rwanda refugee data program** also promote the use of data for civic good and humanitarian purposes (i.e. "data for good").

Table 3.10 – Example learning goals from open data activities.

Case study	Learning goals
A Scuola di OpenCoesione	*"A Scuola di OpenCoesione builds on OpenCoesione data portal* [OpenCoesione is the open government strategy of the Italian Government on Cohesion Policy] *to actively <u>promote the use and reuse of data as a basis for the development of civic awareness and engagement</u>. The application of Open Data to real-life public interventions <u>can stimulate the creation of a "monitorial citizenship"</u> … Indeed, ASOC is mainly about civics and civic education, and complements the standard high school curriculum"* (Ciociola & Reggi, 2015, p. 27).
Alan Walks Wales Dataset	*"The principal value of the open data was to <u>make real the issues that arise when large quantities of personal information become available publicly</u>. This was less <u>using the data itself as using the existence of the data as a provocation for a number of discussion topics</u> including privacy, quantified self, and the value and politics of open data in academia"* (Dix & Ellis, 2015, p. 57). *"The main value here of the open data was the <u>availability of a substantial, reasonably well-documented dataset</u> combining quantitative and qualitative elements. In particular it <u>gave the student exposure to real world sensor and textual data with all the problems that entails</u>"* (Dix & Ellis, 2015, p. 57).
ODEdu: Open Data Education	ODEdu piloted several open data courses. The following are two examples. *Open Data Crash Course* by Aalborg University: "*Open Data Crash Course was a part of a bigger 5-ECTS module called ICT for Learning, Content and Knowledge Management. The trial was run at the beginning of the module, as <u>its learning goal was to help students gain a sufficient overview of different aspects and areas of OD in order to later use this knowledge</u> while working on different assignments presented to them throughout the module. Those tasks were concerned with the promotion and teaching of OD to different target groups*" (Zotou et al., 2018, p. 86). *Advanced Issues on Open Data* course by Association of Information Technology Companies of Northern Greece (SEPVE): "*The second trial that SEPVE implemented was an 8-weeks online course named 'Advanced Issues on Open Data' for private sector employees. The course <u>aimed at providing participants with the theoretical and practical knowledge covering the entire life cycle of open data, from data gathering to the creation of useful information</u>. At the end of the course, students were expected to be <u>able to generate valuable information from open data</u>"* (Huntington, Piscopo, Tarrant, Vacher, & Kaliva, 2018, p. 47).

Case study	Learning goals
Project EDDIE	*"EDDIE is a pedagogical collaboration of environmental scientists and education researchers focused on developing classroom modules that will improve quantitative reasoning, build data manipulation skills, and highlight inherent variability in real data"* (Soule et al., 2018, p. 99). *"The goals of these modules, which follow the 5E learning cycle…, are to develop skills required to manipulate large datasets, conduct authentic investigations, develop reasoning about variability in data, engage students in scientific discourse as they explore large datasets, and foster sound ideas about the nature of environmental science research"* (Carey & Gougis, 2017, p. 1).
Open Data School Russia	*"Open Data lectures and workshops provided basic information on how to search for datasets on the Internet and assess their quality… The Data Driven Journalism track discussed the concept of journalism based on data processing, history of Data Journalism and its pioneers, online tools for data visualization, as well as the techniques of searching the required datasets on the Internet, data processing, and finally creating digital story"* (Radchenko & Sakoyan, 2016, p. 154). *"Data expeditions are educational events aimed at teaching the techniques of open data processing"* (Radchenko & Sakoyan, 2016, p. 156).
Rwanda refugee data program	*"The goal is to promote participants' awareness of their community while gaining skills in collecting and using data"* (Xu & Maitland, 2019, p. 2). *"For each research site, we initially outlined to all the participants the goal of this participatory data management project, which is to empower them to be the leaders in collecting and using relevant data to build their communities"* (Xu & Maitland, 2019, p. 6).

3.4.2.2 *Learning objectives and implementation*

Examples of learning approaches and objectives are provided in Table 3.11. The learning objectives are also very similar – they generally involve gaining specific data analysis skills, such as in data sourcing, cleaning, mining, statistical analysis, interpretation and visualisation. Several learning approaches are used to achieve the learning objectives, which are specific to the types of participants and types of data being engaged with.

ODEdu developed a learning approach specifically for open data – the data-driven problem-based learning (PBL) model. Problem-based learning is recommended for open data education because, due to the nature of open data, **ODEdu** argues that "there is a need to think creatively and critically, and a need to work interdisciplinary and in teams. The development of such competences is vital for the extraction of the real potential of open data, as otherwise professionals and students would remain at the less challenging 'pure' technical level. The real challenge emerges when practitioners want to create new knowledge from open data, in order to innovate and add value to their organizations. Therefore, the competences developed and promoted with PBL are key competences for exploiting the potential of open data" (Camacho, Jonasen, Skov, & Ryberg, 2016).

Project EDDIE aims to provide students with an authentic scientific experience. In each **Project EDDIE** module, a flexible modular "A-B-C" structure is followed:

1. Part A: students are engaged is initial data exploration and skill development using simple analyses that bypass some of the technical challenges associated with the manipulation of data.
2. Part B: students explore and explain more detailed analysis that requires them to independently discuss and decide what analyses are appropriate for the data and explain the implications of results.

3. Part C: students expand on the developed ideas by exploring data from sites of their choosing and/or by exploring questions they have developed (Soule et al., 2018).

This structure, which is loosely adapted from the 5E learning cycle by Bybee et al. (2006), seeks to facilitate students' knowledge construction in a manner that is similar to how scientists construct knowledge themselves. According to Soule et al. (2018), completing **Project EDDIE** modules in pairs or small groups allows students to "engage in social construction of ideas, to design their own research questions, and to build their own inquiry processes and scientific knowledge through evidence-based reasoning… Because EDDIE engages students in these authentic scientific practices, we reason these learning experiences may foster more sophisticated NOS [nature-of-science] understanding."

The **Alan Walks Wales Dataset** was also developed as a tool for students to engage with authentic data and thus gain authentic data analysis experience. In particular, the open data provided students "exposure to real world sensor and textual data with all the problems that entails", in contrast to "very artificial or training data" that do not reflect the messiness and challenges of using large datasets (Dix & Ellis, 2015, p. 57). In this exercise, students were given an open brief to use the data however they chose, allowing students significant autonomy on choosing which kinds of data to focus on and what approaches to use. This was done to develop the student's initiative and sense of ownership of the project outcomes (Dix & Ellis, 2015). By using raw data, students were challenged in tasks of data cleaning, attaining background documentation (as is frequently a challenge when dealing with government open data), and dealing with a very large dataset – all of these challenges are relevant to dealing with open data. As these tasks were rather time-consuming, the authors found a flipped classroom approach was beneficial, as then students could familiarise themselves with the data before class (via videos) and the lecture could then be used to discuss the dataset.

The **Rwanda refugee data program** engages both researchers/service providers and participants in participatory design of an open community data system, in effort to enhance the availability of open data to not just the research community, but also to the general public. The program was implemented as a 5-week training program in UNHCR facilities in Kigali and Huye. Training involved two major components: ICTs supporting the participatory data management tool, and the process of implementing it. The stages of training included: participatory data inventory design, data collection, data analysis, and system management. The data management tool was built using a free and open source software named Open Data Kit (ODK), which is a mobile data collection application developed for collecting, managing, and using data in resource-constrained environments (Open Data Kit, 2019). First, participants were trained in downloading and using the ODK Collect application. Then, participants visited other refugee households to collect community data, which would then be uploaded via the web. Participants were responsible for deciding the type of community data to be collected and who to collect data from. From the data collected, basic data interpretation was conducted by the researchers and participants together on topics participants were interested in. For example, participants were interested in learning additional skills to get a full-time job, and so some wanted to know how they could learn English – the data allowed them to know other refugees who were already fluent. Participants were trained to manage the data server and to create their own data inventory to conduct follow-up studies (Xu & Maitland, 2019).

In **A Scuola di OpenCoesione** and the **Open Data School Russia** both aim to increase awareness of open government data. **A Scuola di OpenCoesione** promotes the use of data from the OpenCoesione data portal (part of the open government strategy of the Italian Government on Cohesion Policy) for the development of civic awareness and engagement. Civics and civics education complement the local standard high school curriculum. **A Scuola di OpenCoesione** is an educational challenge designed for Italian high school students. A blended teaching approach is utilised, combining project-based learning, flipped classroom (with MOOCs before group activities), group activities in class, and online interaction with staff. The course is organised in six main sessions, with each session respectively focusing on public policies, open data analysis, data journalism, citizen monitoring of public funding, on-site visits to the selected publicly-funded projects and interviews with key players involved in the implementation, and a final event where students meet local communities and policymakers to discuss the findings of their investigations. Students select a project based upon data from OpenCoesione (e.g. a large infrastructural project). Then, students use quantitative and qualitative research methods to locate open data sources and to investigate the socio-economic context of the project. Outputs include descriptive statistics, infographics and data mash-ups. From their research, students develop interviews to conduct a citizen monitoring visit to the project site and publish their findings in a report on an open platform. The findings are also shared with the public, in order to stimulate an informed debate involving local communities and the authorities responsible for financing and implementing the project. By working on real-life civic issues, **A Scuola di OpenCoesione** encourages students to come up with original solutions to local challenges and to acquire many different open data and civic monitoring skills.

With the establishment of the Open Government of Russia, it is expected that more and more Russian citizens will be using open data. **Open Data School Russia** was established to spread open data skills such as programming, analysis and visualisation. At **Open Data School Russia**, open data education was implemented via data expeditions, which are project-based and self-directed educational events that taught the techniques of open data processing. Most of these events are carried out with mixed educational principles, combining traditional offline teaching and online interaction. In a data expedition, participants develop a project so that they are able to immediately apply new open data skills and produce real outputs (e.g. a data journalism project where they research, analyse, visualise and publish data in a blog post or article). This learning experience is supplemented with "team work based on peer-learning approach and experience exchange" as participants interact with each other online through a Google Group, exchange their knowledge, experience and findings, provide feedback, share their work and ask questions (Radchenko & Sakoyan, 2016, p. 164).

Table 3.11 – Example learning objectives from open data activities.

Case study	Learning approach	Learning objectives
A Scuola di OpenCoesione	Project-based learning (Ciociola & Reggi, 2015)	"*Focused on real-life civic issues, ASOC forces the students to come up with original solutions to local challenges. Students are stimulated to acquire different skills, from working as part of a team to specific technical abilities such as analysing data or developing multimedia content*" (Ciociola & Reggi, 2015, p. 29).
Alan Walks Wales Dataset	Flipped classroom (Dix & Ellis, 2015)	"*Some learning outcomes were clear from the outset: skills in data cleaning, application of data mining and visualisation techniques… the authors had limited foresight as to the full range of learning that would emerge*" (Dix & Ellis, 2015, p. 58).
ODEdu: Open Data Education	Data-driven problem-based learning (PBL) model (Camacho et al., 2016)	*e-Government BSc Course* by University of Macedonia (Zotou et al., 2018, p. 40): • *Understanding the role and the potential of utilizing information systems in Public Administration* • *Using e-government and e-participation applications* • *Developing simple applications based on open government data.*

Case study	Learning approach	Learning objectives
Open Data School Russia	Project-based learning Self-directed learning Peer-learning and experience exchange Blended learning combining offline teaching and online interaction (Radchenko & Sakoyan, 2016)	*"The first Russian-language Data Expedition (DE1) took place in July 2013. Its declared objective was finding, processing and presenting data regarding universities both in Russia and around the world"* (Radchenko & Sakoyan, 2016, p. 159).
Project EDDIE	Active learning (Soule et al., 2018) A flexible modular "A-B-C" structure loosely based on the 5E learning cycle (Soule et al., 2018) Inquiry-based learning (Soule et al., 2018)	Learning objectives from Stream Discharge Module: • *Students will download, organize and analyze streamflow data.* • *Students will use data to compare short-term and long-term discharge variability, and quantify climate change impacts on water quantity in their region.* • *Students will calculate flood frequency from peak discharge data, and will calculate the effects of urbanization and flood control on flood frequency.* • *Students will develop an understanding of the following scientific concepts:* o *Stream discharge* o *Variability and trends in time series data* o *Peak flow and flood events* o *Flood probability and recurrence interval* o *Effects of urbanization on discharge events* • *Students will develop an understanding of the following statistical concepts:* o *Detecting variation and trends on short and long timescales* o *R-squared* o *Peak event probability*
Rwanda refugee data program	Participatory design (Xu & Maitland, 2019)	Example unavailable

3.4.2.3 *Tools and resources*

The most significant resource is the open data itself, of which there are many sources. **A Scuola di OpenCoesione** and the **Open Data School Russia** were both established closely with the open data initiatives by the Italian and Russian governments respectively. **A Scuola di OpenCoesione** promotes the use of data from the OpenCoesione data portal (part of the open government strategy of the Italian Government on Cohesion Policy), while **Open Data School Russia** promotes the use of data from the Open Government Russia. For **Project EDDIE**, datasets differed for each module (see here) – these datasets include open access data of published research (e.g. the Lake Metabolism Module uses data from a journal article), scientific organisation data portals (e.g. National Snow and Ice Data Center, Global Lake Ecological Observatory Network), and real-time public data portals (e.g. real-time river data via the USGS National Water Information System and the USGS WaterQualityWatch). As part of most **ODEdu** pilot courses, students are introduced to various open data portals to explore (e.g. public transport data by Transport for London, community data by the mySociety social enterprise, civil data by openAfrica, and university-published open data such as the University of Macedonia data portal). On a somewhat "smaller" scale, the **Rwanda refugee data program** utilises data self-collected by the participants (Xu & Maitland, 2019), and the **Alan Walks Wales Dataset** is openly available personal data of the author (Dix & Ellis, 2015).

In a few cases, the resulting output data generated by participants are also fed back to the public domain. With the **Alan Walks Wales Dataset**, the data created by students are made public again via the project website. In doing so, future students and researchers are able to build upon previous work (the tools and processes of which were documented via student reports (Dix & Ellis, 2015). With the **Rwanda refugee data program**, data collected by the participants are stored in a secure server and is openly accessible to all the refugee members of the community through a URL (although the data is not made open to the general public due to the sensitive nature of the data (Xu & Maitland, 2019).

Another form of open resource used for these activities is open source software. For example, with the **Rwanda data refugee program**, the data management tool was built using a free and open source software named Open Data Kit (ODK), which is a mobile data collection application developed for collecting, managing, and using data in resource-constrained environments (Open Data Kit, 2019). In addition to Microsoft Excel, open data was also often analysed via open source software, such as R software (**Project EDDIE**) and GPS Babel (**Alan Walks Wales Dataset**).

3.4.3 Learner responses

In most cases, there has been evidence of improved data analytical skills. Learners generally responded really well to the use of real data, which was a large motivator for participants. Participants found it interesting to engage with real, relatable data and were motivated by being able to produce useful and practical outputs from the data (i.e. can solve a real-world problem). These case studies were therefore generally successful in achieving the learning goal (i.e. to increase awareness of open data, to improve skills in open data, and to promote the use of open data).

Table 3.12 – Example learner responses from open data activities.

	Strengths	Challenges
A Scuola di OpenCoesione (Ciociola & Reggi, 2015)	• Students gained independent problem-solving skills. • Investigating local and concrete issues is a strong motivator for students. • Students are able to contribute practical solutions on the topic they studied.	• Some schools failed to finish the program due to difficulties with students balancing project work while keeping up with the regular school curriculum.
Alan Walks Wales Dataset (Dix & Ellis, 2015)	• Raw data is educationally valuable giving students experience in dealing with data cleaning and related skills. • As co-creators of the data and educational material, students benefit professionally. Allowing students to give feedback on the data also adds value to open data. • Well documented open data is a potentially valuable resource for flipped modes of learning.	• The combination of an open brief and raw data was daunting and added a lot of uncertainty – perhaps a more specific brief and a cleaner dataset may be more helpful for students who are less confident. • It is time consuming for students to "get into" the dataset. • Clear data documentation is essential.
ODEdu: Open Data Education	*Better Data, Better Decisions* VET course (Huntington et al., 2018): • Improved participant knowledge and skill. *Advanced Issues on Open Data* VET course (Huntington et al., 2018):: • Improvement in data skills, including obtaining, scrubbing, exploring, visualising, interpreting, and presenting data. Overall evaluation for university pilots (Konstantinos, Tambouris, Zotou, Panopoulou, & Skov, 2018): • Learning analytics was useful to monitor learning progress and for lecturers to adapt material. • Students benefited from e-learning platform • Students were motivated to participate in the course through exercises and practical experimentation with existing datasets.	*Advanced Issues on Open Data* VET course (Huntington et al., 2018): • More than half students dropped out of course very early due to lack of time, that the course may have been too difficult, and that the course took place in early summer. • Scarce participation in class discussions may have hindered achieving learning outcomes. Overall evaluation for university pilots (Konstantinos et al., 2018): • Students found Moodle complicated and disorganised. • Courses in the platform should be structured more in line with the PBL approach than based on the curriculum units of learning, in order to help students to follow the PBL principles. • Students would like the materials to be more diverse and interactive, with more practical exercises. • Students wanted some improvements in regards to the visual design and responsiveness of the platform. • Students needed more guidance on the PBL approach and on the usage of external software for exploiting Open Data. • Lecturers wished for more collaborative features in the e-learning platform.

	Strengths	Challenges
Open Data School Russia (Radchenko & Sakoyan, 2016)	• Project-oriented format makes it possible for students to immediately apply new skills. • Consultations with experts and encouraging participation via symbolical badges significantly contributed to efficiency of learning process. • Mixed format (combining offline and online activities) results in better performance. • Informal peer-learning projects and MOOCs are low-cost, broadly available and an easily reproduced model which makes them both an excellent tool of educational self-organization, as well as a very efficient supplement to a traditional training course.	None mentioned.
Project EDDIE	• Improved quantitative literacy (Klug, Carey, Richardson, & Gougis, 2017) • Improved spreadsheet skills (O'Reilly et al., 2017). • Increased appreciation for the predictive power of large datasets (Carey, Darner Gougis, Klug, O'Reilly, & Richardson, 2015). • Improved understanding of challenging content, such as climate change (Carey & Gougis, 2017). • Students practice sophisticated cognitive tasks, such as data visualisation and discussion of how spatial and temporal resolution affects ability to detect environmental changes (Soule et al., 2018). • Students experienced gains in understanding of statistical concepts, and comfort and self-reported ability using Excel (Soule et al., 2018).	• Both students and instructors were commonly were frustrated with the Excel barrier – students were unfamiliar with the program, and instructors spent a lot of time explaining procedural details that were disconnected from the learning goals (Soule et al., 2018).

	Strengths	Challenges
Rwanda refugee data program (Xu & Maitland, 2019)	Among 34 participants who answered the survey on perceived effectiveness: • 76% agreed that the data collection improved their awareness of their community. • 68% agreed that data collection helped them engage more with their community. • 41% agreed that data analysis helped them become more aware of the capacities in their community. • 50% agreed that the collected data will be useful in solving problems in their everyday lives. • 41% agreed that helping others using the system could increase their sense of responsibility in building a better community. • 59% expressed that they would like to use the system frequently. • 71% believed that they are confident to use the techniques to conduct similar project for their community in the future.	• 15% found that the system was unnecessarily complex. • 35% indicated that they might need support of a more technical person to be able to use the system. • 9% strongly felt that they needed to learn a lot before they can comfortably use the system.

4 Discussion

4.1 Characteristics of educational open science/innovation activities

This section responds to RQ1: What are the characteristics of educational open science/innovation activities observed?

4.1.1 Various intersections of science/innovation, openness and education

Each of the 24 activities included in this SOTA analysis contain elements in science/innovation, openness and education (Figure 4.1). This broad inclusion was adopted because there are many interpretations of how these three elements may intersect to form an educational open science/innovation activity. For example, there are various ways in which openness is expressed in science and innovation, various scientific knowledge and tools that can be included, and many possible ways how openness can be integrated. This ultimately creates a diverse range of activities of which each can be argued to be an educational open science/innovation activity. Various example interpretations of these activities, as identified from the selected case studies, are summarised in Table 4.1.

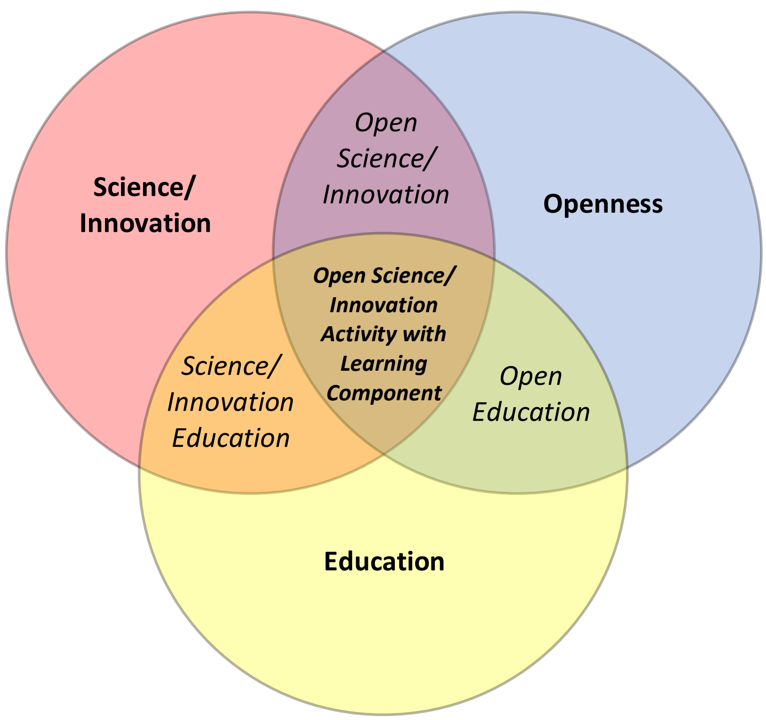

Figure 4.1 – Activities that combine elements of science/innovation, openness and education can be considered as an educational open science/innovation activity. There are many interpretations of how these elements can be combined, examples of which are presented in Table 4.1.

Table 4.1 – Examples of educational open science/innovation activities, combining elements of science/innovation, openness and education. There are many possible interpretations on how these three elements can be combined, resulting in a diverse range of activity types. The following activity types were identified from the case studies examined. Other activity types are possible.

Activity types	Key open concepts	Example case studies
A scientific/innovation activity conducted collaboratively by a diverse community, combining researchers from HEIs (across disciplines and diversity groups), the general public, multiple cultures, multiple age groups, industry and/or government	Open science, citizen science, open innovation	Citizen science activities (e.g. Neighborhood Nestwatch), Open Innovation Laboratories @Tecnológico de Monterrey, Ocean i3, Science at Home's Quantum Moves
A scientific/innovation activity designed and driven by non-academics (i.e. citizen inquiry), perhaps with the guidance of expert mentors	Open science, citizen science, citizen inquiry, open knowledge	nQuire, Rwanda refugee data program, iSCAPE Living Labs
A learning activity that is implemented through participation in a scientific/innovation activity	Open science, citizen science	Many citizen science activities via informal science learning (e.g. City Nature Challenge, Masseeksperiment), or inquiry-based learning (e.g. BOKUroadkill, the NIISS Educational Program)
A learning activity that is implemented using open science/innovation outputs (including open data, open source software/hardware, shared open knowledge by experts)	Open science, open data, open source software/hardware, open knowledge	A Scuola di OpenCoesione, ODEdu, Open Science School, Challenge Based Innovation @IdeaSquare CERN, iSCAPE Living Labs, air:bit
A science/innovation learning activity that is shared as an open educational resource, or is implemented using open educational resources and practices.	Open educational resources, open educational practices	National Geographic Education, OpenSciEd, City Nature Challenge, Science at Home's Quantum Moves
A learning education activity that produces scientific research and innovation outputs that are made open access	Open access, open data	Rwanda refugee data program, Alan Walks Wales Dataset
A learning activity that develops skills necessary for open science/innovation (e.g. improved scientific literacy of non-scientists, open collaboration/innovation skills, open data skills).	Open collaboration/innovation, open science, open knowledge	Challenge Based Innovation @IdeaSquare CERN, Ocean i3, ODEdu, Open Data School Russia, nQuire

4.1.2 Activity products: learning and scientific/innovation outputs

Open science/innovation activities generally have two types of end-products: 1) learning, and/or 2) scientific/innovation outputs. Most of the selected case studies have both learning and scientific/innovation goals, such as in the case of **Neighborhood Nestwatch**, which "engages citizen scientists in the collection of scientific data [scientific/innovation output] and fosters scientific literacy [learning goal]" (Evans et al., 2005, p. 589). In some other cases, there is less emphasis on scientific/innovation outputs and there is more focus on learning, such as in the case of **OpenSciEd**, which aims "to provide students with a coherent experience that is motivated by the students' own desire to explain something they don't understand or to solve a problem [learning goal]" (OpenSciEd, 2019). While not within the scope of this study, it is also possible for certain open science/innovation activities to have scientific/innovation goals without any learning goals.

However, our analysis shows that learning goals and scientific/innovation goals are co-beneficial. First, it is known that partaking in "real" research activity is a major motivator for participants to learn. Open science/innovation products can also be used as educational tools and resources, such as open data (**Alan Walks Wales Dataset**), open software/hardware (**Open Science School**), and open knowledge by experts (**CBI CERN Challenge**).

Second, scientific/innovation outputs can in turn be enhanced by pedagogy. As seen by our case studies, the need for learning in open science/innovation activities mainly results from the involvement of multiple stakeholders of various backgrounds working together, thus requiring participants to acquire new technical and soft skills to facilitate the collaboration. This includes engaging citizens or school children to participate in or conduct their own scientific research (e.g. **Masseeksperiment**, **nQuire**, **iSCAPE Living Labs**), engaging HEI students of multiple disciplinary backgrounds to collaborate with non-HEI stakeholders on an innovative service/product (e.g. **Open ILabs**, **Ocean i3**), or engaging the general public to analyse open government data for civic monitoring (e.g. **A Scuola di OpenCoesione**, **Open Data School Russia**). In all cases, participants needed training to get involved.

Our analysis supports the importance of learning in open science and open innovation. It is important for the learning aspect of open science/innovation activities to be carefully considered, in order to maximise the educational, scientific, innovative and social impact of such activities. The remainder of the discussion collectively explores the learning design of the case studies, to capture the state-of-the-art of pedagogy in open science/innovation activities. In future studies, this information can then be used to determine the next steps of advancing the pedagogical value of open science/innovation activities.

4.2 Learning design of educational open science/innovation activities

This section responds to RQ2: How is learning designed in recent open science/innovation activities?

4.2.1 Topics

Activities with natural/physical science, engineering, multidisciplinary innovation (including arts/science) and data science (including social science data) topics are represented by our case studies. However, the topic for each activity was not usually singular. As with the open nature of many of these activities, case studies often combined topics and participants from multiple fields and backgrounds. Activities such as **CBI CERN**, and **Ocean i3** all involved HEI students across science, humanities and art disciplines to work together, and even encouraged students to collaborate with stakeholders outside HEI settings. While innovation-focused, activities such as **CBI** and **Open Innovation Laboratories** emphasised service design, especially for addressing Sustainable Development Goals. Open data activities also deal with data from a variety of fields, including public government data (e.g. **A Scuola di OpenCoesione**), environmental data (**Project EDDIE**), social science community data (**Rwanda refugee data program**), and biotracker data (**Alan Walks Wales Dataset**). In any given open science/innovation activity, it is likely that multiple topics and perspectives are being discussed.

4.2.2 Learning goals

Despite the large diversity in topics, groups of case studies were found to have very similar learning goals. Case studies were grouped accordingly in our analysis, which allowed the comparison of the different pedagogies used by separate case studies to achieve similar learning goals. Moreover, approaching activities by their learning goals is important for organisers, since these goals shape activity design.

From our selection of case studies, three groups of activities were identified, each with different learning foci (Table 4.2). It is acknowledged that these activity groups are generalised and possibly incomplete due to the limited selection of case studies. Nevertheless, in addition to the ubiquitous goal of improving knowledge on a particular topic, the groups reflect several popular knowledge gaps in which many open science/innovation activities aim to address:

1. Knowledge or awareness of a particular topic (ubiquitous to all activities)
2. Soft and technical skills needed for proper and open science/innovation practice
3. Knowledge of the scientific inquiry method
4. Open data skills

These learning goals originate from higher-level aspirations of improved inclusivity in science/innovation activities, improved social relevance of science/innovation outputs, improved relationships between the general public and HEIs, improved awareness of causes, and fact-based societal change. These learning goals were generally set by the activity organisers (including developers, government departments, government research organisations, libraries, museums, science centres, non-profit organisations, public initiatives, public schools, research/developer consortiums, research institutes, universities, humanitarian aid agency).

*Table 4.2 – From our selection of case studies, three groups of open science/innovation activities were identified, each with different types of learning goals. The groups reflect three important knowledge gaps in which many activities aim to address (not included in this table is the ubiquitous goal of improving knowledge on a particular topic). *The numbers indicate the number of case studies in each group.*

Activity group *	Example learning goals	General description
Activities for developing open collaboration in science and innovation (8) *See Section 3.2*	To develop collaboration skills (interdisciplinary, cross-sectoral, intercultural) for problem solving and innovation. To develop sustained and empowered citizen participation in learning and science.	These activities promote and support open science/innovation practice. To be involved in open science and open innovation projects, stakeholders need to be trained in relevant soft and technical skills. For example, to boost open innovation practice, Ocean i3 conducts workshops for students to improve their cross-cultural communication skills. Likewise, if citizens are being encouraged to conduct their own science/innovation projects, they must first be familiar with the scientific inquiry process. nQuire provides citizens with a framework on how to conduct a scientific investigation. Such soft and technical skills are crucial for the sustained practice of open science and open innovation. As the awareness for such open skills increase, they are also introduced in school-level curricula, such as the National Geographic Learning Framework's emphasis on teamwork to develop collaboration skills.

Activity group *	Example learning goals	General description
		Another important method to promote open science/innovation is to generate a genuine interest for participants to partake in open science/innovation activities. Efforts to boost passion in science/innovation include **OpenSciEd**'s use of storytelling to engage school students with scientific content, and **iSCAPE Living Lab**'s encouragement for participants to develop air quality monitoring projects that interest them and is relevant to their own local communities.
Citizen science activities for inquiry learning (10) *See Section 3.3*	To improve knowledge on a certain topic (including cause awareness and appreciation). To improve understanding of the scientific method.	Many citizen science activities were developed by researchers to crowdsource data collection. In return to participants, it is popular for such activities to promote themselves as educational opportunities through informal science learning (i.e. learning by participation in a real scientific research project). Some activities, including all of our case studies, takes education step further by incorporating additional activities to create a more complete and formal inquiry-based learning approach. As such activities usually involve a niche topic (e.g. primrose distribution data by **Estonia is Looking for Primroses**), these citizen science activities usually aim to spread knowledge and awareness of the specific topic (e.g. the significance of primrose distributions) or the general field (e.g. ecological and environmental appreciation). Topics of citizen science activities can range throughout science, humanities and arts disciplines. Citizen science activities are also good opportunities for participants to understand the scientific inquiry method, which is another common learning goal.
Activities for open data training and innovation (6) *See Section 3.4*	To increase awareness of open data, to improve skills in open data, and to promote the use of open data.	These activities focus on promoting open data literacy and innovation. Open data is a vital skill in the era of open knowledge and research, throughout science, humanities and arts disciplines. No matter which field, the need for open data skills are increasingly important as mass amounts of data becomes public for observation, analysis and transformation. These activities aim to ensure proper data handling by non-experts.

4.2.3 Participants and their role in learning design

Considering the HEI context of INOS, learners can be from within HEI communities (e.g. researchers, university students) as well as outside HEI communities (e.g. general public, school students, industry members). Activities can also be conducted for these groups separately or together. The type of participants is dependent upon the learning goals of the activity. For example, some activities encourage and upskill collaboration between researchers and the general public – in these cases, both communities are involved (e.g. **Neighborhood Nestwatch**). Some other activities may focus on upskilling a specific target audience.

It is important to note that participants in open science/innovation activities are sometimes given agency to be part of the learning design themselves. Overall, there is an emphasis on creating activities that are socially needed and relevant. Thus, many of the activities were designed considering the interests and needs of the participants. While this information was not available for our case studies, it is assumed that some activities may have consulted participants to understand their interests and needs.

Participant agency in learning design is also created through the project-based learning approaches adopted by organisers (described further in Section 4.2.4). For example, many of our cases studies adopted project-based learning approaches, which provided participants the freedom to independently ideate a project and to decide which skills were necessary to complete it. Participants here set their own learning objectives and control their learning outcomes.

Another method to understand participant needs is via learner responses. However, this is not collected by many activities (described further in Section 4.3). Learner responses are a valuable opportunity to understand the needs of participants and their response to the activity design, which is important to reiteratively improve the educational quality and social relevance of the activities.

4.2.4 Learning approaches

To achieve the learning goals, many different learning approaches have been cited, which themselves distil down to four general approaches: project-based learning, inquiry-based learning, collaborative learning and blended learning (Table 4.3). The appropriate learning approach for an activity depends on its learning goals and objectives. Each learning approach has its benefits. For example:

1. Project-based learning: this approach is good for developing innovation/collaboration skills, which are important for open science/innovation practice.
2. Inquiry-based learning: this approach is good for demonstrating the scientific inquiry process and teaching scientific knowledge.
3. Collaborative learning: this approach is conducive for creative thinking and open-ended learning, which are emphasised in open educational practices, and are important skills in open science/innovation practice.
4. Blended learning: a combination of online and classroom tasks enables effective use of available open resources. Open science/innovation activities often utilise open access resources available online (e.g. open data, open software, OER). Participants typically explore the online open resources independently, and then use the classroom for more collaborative and engaged learning tasks.

Learning approaches are often combined and adapted to suit the learning goals and objectives. For example, in **Masseeksperiment** learning activities, school students are exposed to inquiry-based learning through experiments. School students are also given online resources, such as online videos and infographics, to self-study more information to help in their experiments (i.e. blended learning). In another example, **CBI CERN** combines principles of project-based and collaborative learning, as students are given the task to create an innovative product/service together in a multidisciplinary team.

Beyond this study, informal science learning (i.e. learning by participation) is a common learning approach used in many citizen science activities. Informal learning has produced some learning success (Crall et al., 2012; Cronje et al., 2011; Phillips et al., 2019; Trumbull, Bonney, Bascom, & Cabral, 2000; Villasclaras Fernandez et al., 2013). For instance, informal learning has been found useful for increasing awareness of local community issues and to improve understanding of the scientific inquiry process (Jenkins, 2011). However, many studies also show that participation alone is not sufficient to ensure learning, as seen by insignificant improvements to knowledge in activities where pedagogy was not explicitly considered (Groulx, Brisbois, Lemieux, Winegardner, & Fishback, 2017; Jordan et al., 2011; Land-Zandstra, Devilee, Snik, Buurmeijer, & Van Den Broek, 2016; Martin, 2017; Pandya & Dibner, 2019; Phillips et al., 2019; Powell & Colin, 2008; Raddick, Prather, & Wallace, 2019).

If learning is a desired product of the activity, it is argued that formal learning design should be adopted to better deliver this goal. A natural method to do so is to embed participation in citizen science activities into an inquiry-based learning format. As done by the case studies in Section 3.3, this can be done by offering supplementary learning activities (pre- and post-data collection phases) to complete the inquiry process – see Section 3.3.2.2 for more explanation. Another important benefit of adopting proper learning design is that it should include the collection of learner responses, which is useful information for the reiterative improvement of the activity's design and impact (Dalziel et al., 2016).

*Table 4.3 – Summary of learning approaches used in educational open science/innovation activities, based on the selected case studies. *The numbers indicate the number of case studies that explicitly refer to the learning approach in their documentation.*

Main and similar learning approaches*	General learning sequence	Advantages of use and learning outcomes
Project-based learning (4) • Problem-based learning (3) • Authentic learning (3) • Challenge-based learning (2) • Design-based learning (2) • Hands-on learning (2) • Service learning (2) • Self-directed learning (1) • Learning by doing (1)	• Participants are given a broad task brief. • Participants perform their own background research to identify a real-world issue they wish to solve. • Participants work in multidisciplinary teams. • Participants generate multiple ideas and test them. • Participants fine-tune their ideas and produce a final output. • Participants present their project.	• Participants gain skills in cross-boundary collaboration (i.e. open innovation) between HEIs, the general public, industry and government (as well as across disciplines, sectors and cultures). • Effective learning of technical skills as participants have the opportunity to apply newly learnt skills in projects. • Participants produce solutions to real-world challenges. • Participants are motivated by being able to participate in and produce solutions to authentic, real-world challenges, especially when the challenges were identified by the participants themselves. • Participants are motivated by projects designed by themselves. • Participants learn topics and skills that are relevant and useful to them.

Main and similar learning approaches*	General learning sequence	Advantages of use and learning outcomes
Inquiry-based learning (6) • Citizen inquiry (1) • 5E learning cycle (1) • Place-based learning (2) • Research-based learning (1) • Process-oriented learning (1) • Phenomena-based teaching (1) • Learning-for-use (1) • *Informal science learning* [not a formal learning approach]*	• Participants are provided background information on a certain topic, or are allowed to explore a topic of their own interest. • Participants are given or are asked to identify a research question. • Participants are given or are asked to design a methodology to address the research question. • Participants gather evidence and analyse it to respond to the research question. • Participants share their findings. • Mentors provide guidance to participants to assist in their progress.	• Activities elicit participant curiosity on a certain phenomenon, topic or issue, which is a significant motivator for continued and sustained learning. • Personal curiosity, especially on topics that participants are personally interested in, are key for sustained interest. • Greater understanding of the scientific research method from participation. • Participants learn to ask questions and to construct knowledge in a manner similar to how scientists do. • Participants learn topics and skills that are relevant and useful to them.
Collaborative learning • Learning as conversation (1) • Case-based learning (1) • Peer-learning and experience exchange (1) • Role-play (1)	• Participants are asked to examine and to discuss an issue together. • Used to complement project-based and inquiry-based learning activities. • Learner-centred approach with intense interaction between participants.	• Participants are exposed to different perspectives that are vital for innovations and solutions for modern-day wicked problems. • Participants are able to discuss and construct knowledge collaboratively. • Participants help each other with learning.
Blended learning (2) • Online learning via MOOCs (2) • Flipped classroom (1) • Game-based learning (1)	• Participants learn from a combination of online and classroom teaching methods. • Participants are asked to exploring information via online MOOCs or other online resources before commencing the activity. • Used to complement project-based and inquiry-based learning activities. • Online games may also be used to complement classroom teaching activities.	• Open access resources (e.g. open data, open software, OER) are typically shared online. • With activities that require significant background knowledge, a flipped classroom was beneficial so that the activity time can be dedicated towards more difficult/engaged learning tasks. • Online learning via MOOCs is a useful tool for pre-activity learning in a flipped classroom. • Online resources are a useful framework for self-directed learning. • Online platforms are useful for participant collaboration. • Online platforms are useful to provide learning analytics for instructors. • Participants are motivated and engaged via game elements.

4.2.5 Learning settings, tools and resources

In terms of time, some activities were conducted within a day (e.g. short projects integrated into a school or university lesson), while others were long projects requiring a few days to a few weeks to complete (e.g. activities involving days or weeks-long citizen science data collection periods). There were also some open science/innovation courses that took a month to six months to complete.

Learning is conducted in many different spaces. This includes classrooms, the outdoors, public spaces, personal homes, collaboration/innovation facilities, and virtual (online, computer-based and/or mobile phone-based).

Many citizen science activities, especially those with natural science topics, are conducted in the outdoors and public spaces so that participants can explore and collect environmental data. In the case of **Neighborhood Nestwatch**, participants collected bird monitoring information from their personal backyards. Activities that focus on collaboration and innovation provide dedicated collaboration/innovation facilities, such as **CBI CERN**'s IdeaSquare space and the **Open Innovation Laboratories at Tecnológico de Monterrey**. These facilities typically include prototyping areas (e.g. fablabs, makerspaces), as well as spaces for participants to discuss ideas (e.g. meeting rooms). More formal settings such as classrooms can also be offered as collaboration spaces for students to discuss their projects.

Online/computer-based learning settings are also popular to deliver online resources, including learning material (e.g. educational videos and games), as well as learning tools (e.g. open data and open software). Mobile phones are also often used as an easy and mobile tool to collect data for outdoors-based citizen science activities (e.g. iNaturalist app in **City Nature Challenge**).

For some cases, the learning setting is flexible, such as activities that are offered as OER lesson plans (e.g. **National Geographic Education**, **OpenSciEd**), MOOCs, online games (e.g. **Science at Home's Quantum Moves**), or self-directed learning settings (e.g. **nQuire**). In these activities, target participants are also flexible. For example, **Science at Home's Quantum Moves** games have been implemented across high schools, university classes, public events and lectures.

Tools and resources used to implement these activities are summarised in Table 4.4.

Table 4.4 – Summary of tools and resources used in educational open science/innovation activities, based on the selected case studies.

Tools and resources	General description and advantages of use
Collaboration/Innovation facilities	• Facilities for students to ideate, prototype, test and present their products of their collaborations. • Facilities may include technologies for prototyping innovations, such as makerspaces, fab labs, virtual reality platforms. • Facilities may also include collaboration spaces, such as meeting rooms • Collaboration spaces may also be virtual via an online platform. • Dedicated spaces for innovation encourage participants to engage in research and innovation in their own terms and through their own means. Such an approach recognises the role of people as social agents capable of affecting change as well as their hopes and beliefs, interests, skills, and aspirations.

Tools and resources	General description and advantages of use
Expert mentors	• Mentors better acquaint participants with available resources, guide participant progress, and share their expertise. • Useful for project-based learning and inquiry-based learning activities.
Apps for citizen science activities	• Useful for data collection in citizen science activities. • Mobile apps typically provide instructions on how to collect data, as well as provide basic background scientific information. • Easy and quick for participants to have the necessary tools and resources needed to participate in the activity. • Mobile phones are easy to carry. • Assists with mass data collection and upload. Quick transfer of data to researchers organising the citizen science activity. • Mobile apps are customisable to suit the design of the activity.
Online resources	• For citizen science activities, websites provide logistical information of the activity (e.g. date and venue), background information on the motivation to collect the type of data, background information on the organisers, and contact information. • Websites may act as a compendium for educational resources. This may be in the form of educational and demonstration videos, articles/blogposts, webinars and podcasts generally targeted towards participants who are interested in learning more scientific information.
Open data	• Citizen science activities may provide open access to the datasets collected by participants, via data portals on their websites. Visitors are typically able to view, visualise, select and/or download data. • To demonstrate the use of the data from citizen science activities, websites also usually feature a list of publications that have resulted from the datasets. • Sources of open data include, government-published open data, open data from published research, data portals by scientific organisations, community-collected open data, and self-collected open data. • In open data activities, the resulting output data generated by participants are also fed back to the public domain.
Open educational resources	• Some initiatives may provide external educators (e.g. school teachers) with educational resources, which is typically made available online. • This includes lesson plans, classrooms, infographics, worksheets, sample presentations and games. • OER are flexible, allowing external educators to customise activities to suit their own curricula.
Open source software/hardware	• Open source software/hardware are typically low-cost (most open software is free), making the scientific tools more accessible for the general public, including resource-constrained communities. • Open source software/hardware specifications are open access, allowing anyone to make innovative customisations or add-ons.
Specialist scientific equipment	• Some activities may require data collection using specialist scientific equipment, such as air quality sensors or water quality monitoring kits. • Equipment are be lent by researchers, who train participants on how to use them.

4.3 Learner responses to educational open science/innovation activities

This section responds to RQ3: What are the learner responses resulting from activity design decisions?

Learner responses capture many different types of information about student learning, such as learning outcomes, competencies, skills and understanding (Dalziel et al., 2016). This information, which is important for iterative learning design improvement, can be collected via feedback (e.g. feedback forms, course surveys), assessments (e.g. quizzes, assignments), learner analytics (statistical data on learners), and evaluations (learners' perspective on learning designs).

As seen from the 24 case studies, there is limited available information on learner responses of open science/innovation activities. Ideally, learner responses should always be collected as part of the learning design process (Dalziel et al., 2016). However, learner responses could only be sourced for 12 of the case studies (it is noted that the other activities may have chosen to not make their learner responses publicly available).

Table 4.5 provides an overview of learning design strengths and challenges in activities (framed as motivators and challenges for learning), based on available learner responses. Based on the available information on these case studies, motivators of learning in open science/innovation activities include active learning, authenticity, learner-centred learning, the use of technology, personal mentorship and guidance from experts. Challenges of learning include initial difficulties for participants to learn unfamiliar open skills, and that significant time and effort may be required to develop a pedagogically-sound open science/innovation activity.

Table 4.5 – Overview of motivators and challenges of learning in educational open science/innovation activities, based on learner responses of the selected case studies.

Motivators for learning	Challenges for learning

• Active learning is an efficient learning approach, leading to improved knowledge and skills.
• Authentic experiences develop relevant and useful skills. For example:
  ○ Working in multidisciplinary teams is a successful tool to enhance collaboration and innovation skills.
  ○ Authentic open data demonstrates to participants the messy nature of raw data, providing them the opportunity to develop relevant skills to manage the data
  ○ Project-based learning makes it possible for students to identify useful skills and be able to immediately apply them.
• Authentic experiences motivate participants to learn. For example:
  ○ Participants perceive real-world data as more interesting than “artificial” data constructed for the learning activity.
  ○ Investigating real-world issues or participating in real-world scientific research projects is a strong motivator for students, who therefore feel like they are able to have real-world impact via their participation.
• Participants are motivated to carry out projects that are self-ideated and self-designed. For example:
  ○ Participants are interested in topics they are genuinely curious about.
• Participants are motivated by the use of technology, as it makes for an efficient, enjoyable activity (e.g. using mobile phones is convenient to collect data, online platforms can establishment earning communities)
• Participants respond well to personal mentorship and guidance from experts.
• Participants are motivated by game-elements.
• Mixed format (combining offline and online activities) results in better performance. Online resources complement classroom learning tasks and boosts overall learning.
• With activities that require significant background knowledge, a flipped classroom was beneficial so that the activity time can be dedicated towards more difficult/engaged learning tasks.
	• Learning open skills may be initially frustrating for those unfamiliar.
	• If the activity is extracurricular, the activity may be time-intensive and challenging for participants to complete on top of regular school or coursework.
	• Effort may be needed to maintain participant interests during long-term activities. For example:
	  ○ Facilitators need to continually engage and support participants in learner-centred activities.
	• Applicable to many citizen science activities: if not explained, participants may not understand the overall goals of the research project and how the data would be used. Learning may be hindered when context is not sufficiently provided.
	• Participants react negatively and are demotivated to participate when online resources do not run smoothly (e.g. app malfunction, website issues, disorganised online platforms and content).
	• Gamification may distract learners from original learning objectives.

5 Conclusion and summary

Open science (including citizen science) and open innovation activities are transparent, accessible, shareable and open to participation. Open practice improves the quality of scientific and innovation outputs, as well as promote public engagement with science and technology, openness and active citizenship.

Learning plays a key role in enabling open participation in open science and open innovation activities, and in improving the quality of their outputs. For example, citizen science activities are often used to improve public awareness on contemporary causes, while events such as hackathons and innovation sprints are used to improve public literacy on important 21st Century skills. Learning also occurs when stakeholders of different backgrounds (across fields, sectors or communities) collaborate on a project, requiring participants to acquire new technical and soft skills to facilitate the collaboration.

Therefore, it is argued that the educational, scientific, innovative and social impact of these activities would be optimised if the learning components were grounded with a solid pedagogy. As many HEIs are involved with organising such activities, the INOS Project aims to improve their design to help enhance the impacts of these endeavours.

This SOTA analysis assessed the current status of learning design in open science/innovation learning activities, in view to its improvement. This included reviewing learning approaches and identifying their strengths and challenges. Twenty-four case studies were gathered using a scoping literature review and desktop research. Case studies were selected if 1) they included elements of science/innovation, openness and education, and if 2) documented evidence of learning design (e.g. a lesson plan) was available.

Activities with natural/physical science, engineering, multidisciplinary innovation (including arts/science) and data science (including social science data) topics were represented by our case studies, which were also conducted internationally. Based on our case selection, there are many possible types of open science activities with a learning component, such as scientific/innovation activities designed and driven by non-academics (i.e. citizen inquiry) learning activities implemented using open science/innovation outputs (e.g. open data, open source software/hardware), learning activities that produce open scientific research and innovation outputs, and science/innovation learning activities shared as open educational resources.

Despite the diversity, collective analysis of the case studies revealed three activity sub-groups each with similar learning goals. In addition to the ubiquitous goal of improving knowledge on particular topics, these groups reflect popular knowledge gaps that open science/innovation activities aim to address:

1. Knowledge or awareness of a particular topic (ubiquitous to all activities)
2. Soft and technical skills needed for proper and open science/innovation practice
3. Knowledge of the scientific inquiry method
4. Open data skills

Grouping activities by their learning goals was more effective than grouping activities by topic (e.g. environment, engineering, design, social science etc.) for several reasons. First, open science/innovation activities typically combined multiple topics and involved participants from different backgrounds, which made the topic difficult and redundant to define. Grouping activities by their learning goals is also more inclusive to various disciplines – for example, any scientific and social scientific discipline may be interested in improving knowledge of the scientific inquiry method. Throughout science, humanities and arts disciplines, the need for open data skills are increasingly important as mass amounts of data becomes public for observation, analysis and transformation. Moreover, approaching activities by their learning goals is important for organisers, since these goals ultimately shape activity design.

For example, the type of participants is dependent upon the learning goals of the activity. Considering the HEI context of INOS, learners can be from within HEI communities (e.g. researchers, university students) as well as outside HEI communities (e.g. general public, school students, industry members). Activities can also be conducted for these groups separately or together. In the case studies, participants are sometimes given agency to be part of the learning design themselves. Participant agency in learning design is mostly created through the project-based learning approaches adopted by organisers. However, there is the potential to improve participant involvement in learning design at the planning stage and through the collection of learner responses, which is unfortunately not collected by many activities (learner responses include feedback, assessments, learner analytics and evaluations).

From the case studies, four main learning approaches were identified: project-based learning, inquiry-based learning, collaborative learning and blended learning. Learning approaches are often combined and adapted to suit the learning goals and objectives. Each learning approach has its benefits to open science/innovation activities. For example:

1. Project-based learning: this approach is good for developing innovation/collaboration skills, which are important for open science/innovation practice.
2. Inquiry-based learning: this approach is good for demonstrating the scientific inquiry process and teaching scientific knowledge.
3. Collaborative learning: this approach is conducive for creative thinking and open-ended learning, which are emphasised in open educational practices, and are important skills in open science/innovation practice.
4. Blended learning: a combination of online and classroom tasks enables effective use of available open resources. Open science/innovation activities often utilise open access resources available online (e.g. open data, open software, OER). Participants typically explore the online open resources independently, and then use the classroom for more collaborative and engaged learning tasks.

Beyond this study, informal science learning (i.e. learning by participation) is a common learning approach used in many citizen science activities. While there is some documented evidence that informal learning can be successful, many studies also show that participation alone is not sufficient to ensure learning. If learning is a desired product of the activity, it is argued that formal learning design should be adopted to better deliver this goal. As done by the citizen science case studies included in this report, a natural method to do so is to embed participation in citizen science activities into an inquiry-based learning format.

Learning can be conducted in many different settings. This included classrooms, the outdoors, public spaces, personal homes, collaboration/innovation facilities, and virtual (online, computer-based and/or mobile phone-based). In many citizen science activities, especially those with natural science topics, are conducted in the outdoors and public spaces so that participants can explore and collect environmental data. Activities that focus on collaboration and innovation provide facilities such as prototyping areas (e.g. fablabs, makerspaces) and meeting rooms for group discussions. Online/computer-based learning settings are also popular to deliver online resources, including learning material and tools. Mobile phones are also often used as an easy and mobile tool to collect data for outdoors-based citizen science activities. For some cases, the learning setting was flexible, such as activities that are offered as OER lesson plans, massive open online courses, online games, or self-directed learning settings. In these activities, target participants may also be flexible.

Overall, there is lack of information on learner responses of open science/innovation activities. To make future improvements to teaching practices in open science/innovation activities, it is important for more activities to collect learner responses (which can take the form of feedback, learning assessments, learner analytics and evaluation). There is also limited literature on the pedagogies of these activities. Based on the available information on these case studies, motivators of learning in open science/innovation activities include active learning, authenticity, learner-centred learning, the use of technology, personal mentorship and guidance from experts. Challenges of learning include initial difficulties for participants to learn unfamiliar open skills, and that significant time and effort may be required to develop a pedagogically-sound open science/innovation activity.

References

Aristeidou, M., Scanlon, E., & Sharples, M. (2017). Design processes of a citizen inquiry community. In *Citizen Inquiry: Synthesising Science and Inquiry Learning* (pp. 210–229). https://doi.org/10.4324/9781315458618

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Astra. (2019). Til undervisningen. Retrieved December 9, 2019, from Natur Videnskabs Festival website: https://naturvidenskabsfestival.dk/supplerende-forloeb-og-aktiviteter

Auener, S., Daugbjerg, P. S., Nielsen, K., & Sillasen, M. K. (2018). *Engineering i skolen: hvad, hvordan, hvorfor*. VIA University College.

Bjælde, O. E., Pedersen, M. K., & Sherson, J. (2014). Gamification of Quantum Mechanics Teaching. *Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*, 218–222. Retrieved from http://arxiv.org/abs/1506.08128

Bliss, T. J., & Smith, M. (2017). A Brief History of Open Educational Resources. *Open: The Philosophy and Practices That Are Revolutionizing Education and Science*, 9–27. https://doi.org/10.5334/bbc.b

Bolus, S., Herben, R., & Wynn, K. (2016). *Exploring Estuaries: A teacher's guide to the estuaries in Victoria*. Corangamite CMA and EstuaryWatch Victoria.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2–16. https://doi.org/10.1177/0963662515607406

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Next steps for citizen science. *Science*, *343*(6178), 1436–1437. https://doi.org/10.1126/science.1251554

Butcher, N. (2015). A Basic Guide to Open Educational Resources (OER). In A. Kanwar & S. Uvalic-Trumbic (Eds.), *Wirtschaftsinformatik* (Vol. 54). https://doi.org/10.1007/s11576-012-0326-2

Bybee, R. W., Taylor, J. a, Gardner, A., Scotter, P. V, Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications. *BSCS*, (September 2015), 1–19. https://doi.org/10.1017/CBO9781107415324.004

Camacho, H., Jonasen, T. S., Skov, M., & Ryberg, T. (2016). Data-Driven PBL model. In *ODEdu: Open Data Education*. Retrieved from http://odedu-project.eu/wp-content/uploads/2017/08/ODEdu_D21_DataDrivenPBLModel_V1b.pdf

Camilleri, A. F., & Ehlers, U.-D. (2012). Mainstreaming Open Educational Practice Recommendations for Policy. In *OPAL Consortium*. Retrieved from http://efquel.org/wp-content/uploads/2012/03/Policy_Support_OEP.pdf

Camprodon, G., González, Ó., Barberán, V., Pérez, M., Smári, V., de Heras, M. Á., & Bizzotto, A. (2019). Smart Citizen Kit and Station: An open environmental monitoring system for citizen participation and scientific experimentation. *HardwareX*, *6*, 1–33. https://doi.org/10.1016/j.ohx.2019.e00070

Carey, C. C., Darner Gougis, R., Klug, J. L., O'Reilly, C. M., & Richardson, D. C. (2015). A Model for using Environmental

Data-Driven Inquiry and Exploration to Teach Limnology to Undergraduates. *Limnology and Oceanography Bulletin*, *24*(2), 32–35. https://doi.org/10.1002/lob.10020

Carey, C. C., & Gougis, R. D. (2017). Simulation Modeling of Lakes in Undergraduate and Graduate Classrooms Increases Comprehension of Climate Change Concepts and Experience with Computational Tools. *Journal of Science Education and Technology*, *26*(1), 1–11. https://doi.org/10.1007/s10956-016-9644-2

CERN. (n.d.). Challenge Based Innovation. Retrieved December 18, 2019, from https://www.cbi-course.com/programme/

Charosky, G., Leveratto, L., Hassi, L., Papageorgiou, K., Ramos-Castro, J., & Bragos, R. (2018). Challenge based education: An approach to innovation through multidisciplinary teams of students using Design Thinking. *Proceedings of 2018 Technologies Applied to Electronics Teaching, TAEE 2018*. https://doi.org/10.1109/TAEE.2018.8476051

Chesbrough, H., & Crowther, A. K. (2006). Beyond high tech: Early adopters of open innovation in other industries. *R and D Management*, *36*(3), 229–236. https://doi.org/10.1111/j.1467-9310.2006.00428.x

Ciociola, C., & Reggi, L. (2015). A Scuola di OpenCoesione: From Open Data to Civic Engagement. In *Open Data As Open Educational Resources: Case Studies of Emerging Practice* (pp. 26–37). https://doi.org/http://dx.doi.org/10.6084/m9.figshare.1590031

City Nature Challenge. (n.d.). Education Toolkit. Retrieved December 9, 2019, from City Nature Challenge 2020 website: http://citynaturechallenge.org/education-toolkit/

Couros, A., & Hildebrandt, K. (2016). Designing for Open and Social Learning. In G. Veletsianos (Ed.), *Emergence and Innovation in Digital Learning* (pp. 143–161). https://doi.org/doi:10.15215/aupress/9781771991490.01

Crall, A. W., Jordan, R., Holfelder, K., Newman, G. J., Graham, J., & Waller, D. M. (2012). The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. *Public Understanding of Science*, *22*(6), 745–764. https://doi.org/10.1177/0963662511434894

Cronin, C. (2017). Openness and praxis: Exploring the use of open educational practices in higher education. *International Review of Research in Open and Distance Learning*, *18*(5), 15–34. https://doi.org/10.19173/irrodl.v18i5.3096

Cronin, D. P., & Messemer, J. E. (2013). Elevating Adult Civic Science Literacy Through a Renewed Citizen Science Paradigm. *Adult Learning*, *24*(4), 143–150. https://doi.org/10.1177/1045159513499550

Cronje, R., Rohlinger, S., Crall, A., & Newman, G. (2011). Does Participation in Citizen Science Improve Scientific Literacy? A Study to Compare Assessment Methods. *Applied Environmental Education and Communication*, *10*(3), 135–145. https://doi.org/10.1080/1533015X.2011.603611

Dalziel, J., Conole, G., Wills, S., Walker, S., Bennett, S., Dobozy, E., … Bower, M. (2016). The Larnaca Declaration on Learning Design. *Journal of Interactive Media in Education*, *2016*(1), 1–24. https://doi.org/10.5334/jime.407

Daniel-Gittens, K. (2016). Open University Model. In S. L. Danver (Ed.), *The SAGE Encyclopedia of Online Education* (pp. 883–885). Thousand Oaks, California: SAGE Publications.

de la Fuente, G. B. (n.d.). What is Open Science? Introduction. Retrieved January 8, 2020, from Foster Open Science website: https://www.fosteropenscience.eu/content/what-open-science-introduction

Department of Childhood Education and Care. (2015). *EDU 346- Science in the Elementary School with Field*

Experience. Salem State University.

DeRosa, R., & Robinson, S. (2017). From OER to Open Pedagogy: Harnessing the Power of Open. *Open: The Philosophy and Practices That Are Revolutionizing Education and Science*, 115–124. https://doi.org/10.5334/bbc.i

Dix, A., & Ellis, G. (2015). The Alan Walks Wales Dataset: Quantified self and open data. In *Open Data as Open Educational Resources* (pp. 56–66).

Edelson, D. C. (2001). Learning-for-Use in Earth Science. *Bringing Research on Learning to the Geosciences*, 1–9.

Eestimaa Looduse Fond. (2019). „Eesti otsib nurmenukke" juhend [Teacher's Guide]. Retrieved December 10, 2019, from Eesti otsib nurmenukke website: https://nurmenukk.ee/juhendid

Ehlers, U. (2011). Extending the Territory: From Open Educational Resources to Open Educational Practices. *Journal of Open, Flexible and Distance Learning*, *15*(2), 1–10.

European Commission. (2016). *Open innovation, open science, open to the world: a vision for Europe*. Brussels: European Commission.

European Commission. (2018). *OSPP-REC: Open Science Policy Platform Recommendations*. https://doi.org/10.2777/958647

Euskampus. (2019). Proyecto Ocean i3. Retrieved December 12, 2019, from Euskampus website: https://euskampus.eus/en/programmes-en/euskampus-bordeaux/ocean-i3

Evans, C., Abrams, E., Reitsma, R., Roux, K., Salmonsen, L., & Marra, P. P. (2005). The Neighborhood Nestwatch program: Participant outcomes of a citizen-science ecological research project. *Conservation Biology*, *19*(3), 589–594. https://doi.org/10.1111/j.1523-1739.2005.00s01.x

Fee, J. M. (2015). *BirdSleuth: Investigating Evidence*. Ithaca, NY: Cornell Lab of Ornithology.

Fermín Serrano Sanz, Holocher-Ertl, T., Kieslinger, B., García, F. S., & Silva, C. G. (2014). *White paper on Citizen Science for Europe*. https://doi.org/10.2307/25305584

Fjukstad, B., Angelvik, N., Grønnesby, M., Hauglann, M. W., Gunhildrud, H., Rasch, F. H., … Bongo, L. A. (2019). Teaching electronics and programming in Norwegian schools using the air:bit sensor kit. *Annual Conference on Innovation and Technology in Computer Science Education*, 374–380. https://doi.org/10.1145/3304221.3325527

Fjukstad, B., Angelvik, N., Hauglann, M. W., Knutsen, J. S., Grønnesby, M., Gunhildrud, H., & Bongo, L. A. (2018). Low-cost programmable air quality sensor kits in science education. *Proceedings of the 49th ACM Technical Symposium on Computer Science Education*, 227–232. https://doi.org/10.1145/3159450.3159569

FOSTER Plus. (n.d.). Open Science Definition. Retrieved November 19, 2019, from Foster Open Science website: https://www.fosteropenscience.eu/foster-taxonomy/open-science-definition

Groulx, M., Brisbois, M. C., Lemieux, C. J., Winegardner, A., & Fishback, L. A. (2017). A Role for Nature-Based Citizen Science in Promoting Individual and Collective Climate Change Action? A Systematic Review of Learning Outcomes. In *Science Communication* (Vol. 39). https://doi.org/10.1177/1075547016688324

Hassi, L., Ramos-castro, J., Leveratto, L., Kurikka, J. J., Charosky, G., Utriainen, T. M., … Nordberg, M. (2016). Mixing Design, Management and Engineering Students in Challenge-Based Projects. *Proceedings of the 12th International CDIO Conference, Turku University of Applied Sciences*.

Hautamäki, A., & Oksanen, K. (2016). Sustainable innovation: Solving wicked problems through innovation. *Open Innovation: A Multifaceted Perspective*, *1*, 87–110. https://doi.org/10.1142/9789814719186_0005

Hegarty, B. (2015). Attributes of Open Pedagogy: A Model for Using Open Educational Resources. *Educational Technology*, (July-August), 3–13. Retrieved from https://twitter.com/open

Heigl, F., & Zaller, J. G. (2014). Using a Citizen Science Approach in Higher Education: a Case Study reporting Roadkills in Austria. *Human Computation*, *1*(2). https://doi.org/10.15346/hc.v1i2.7

Herodotou, C., Aristeidou, M., Sharples, M., & Scanlon, E. (2018). Designing citizen science tools for learning: lessons learnt from the iterative development of nQuire. *Research and Practice in Technology Enhanced Learning*, *13*(1), 1–23. https://doi.org/10.1186/s41039-018-0072-1

Horn, G. Van, Aodha, O. Mac, Song, Y., Cui, Y., Sun, C., Shepard, A., … Belongie, S. (2018). The iNaturalist Species Classification and Detection Dataset. *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 8769–8778. https://doi.org/10.1109/CVPR.2018.00914

Huntington, L., Piscopo, A., Tarrant, D., Vacher, E., & Kaliva, E. (2018). *VET pilots evaluation report*. ODEdu: Open Data Education.

iNaturalist. (2019). iNaturalist. Retrieved December 9, 2019, from https://www.inaturalist.org/

iSCAPE. (2016). About. Retrieved December 10, 2019, from iSCAPE Living Labs Platform website: https://livinglabs.iscapeproject.eu/about/

Jenkins, L. L. (2011). Using citizen science beyond teaching science content: A strategy for making science relevant to students' lives. *Cultural Studies of Science Education*, *6*(2), 501–508. https://doi.org/10.1007/s11422-010-9304-4

Jensen, M. B., Utriainen, T. M., & Steinert, M. (2018). Mapping remote and multidisciplinary learning barriers: lessons from challenge-based innovation at CERN. *European Journal of Engineering Education*, *43*(1), 40–54. https://doi.org/10.1080/03043797.2017.1278745

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., & Ehrenfeld, J. G. (2011). Knowledge Gain and Behavioral Change in Citizen-Science Programs. *Conservation Biology*, *25*(6), 1148–1154. https://doi.org/10.1111/j.1523-1739.2011.01745.x

Klug, J. L., Carey, C. C., Richardson, D. C., & Gougis, R. D. (2017). Analysis of high-frequency and long-term data in undergraduate ecology classes improves quantitative literacy. *Ecosphere*, *8*(3). https://doi.org/10.1002/ecs2.1733

Kobori, H., Dickinson, J. L., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., … Miller-Rushing, A. J. (2016). Citizen science: a new approach to advance ecology, education, and conservation. *Ecological Research*, *31*(1), 1–19. https://doi.org/10.1007/s11284-015-1314-y

Konstantinos, T., Tambouris, E., Zotou, M., Panopoulou, E., & Skov, M. (2018). *University pilots evaluation report*. ODEdu: Open Data Education.

Land-Zandstra, A. M., Devilee, J. L. A., Snik, F., Buurmeijer, F., & Van Den Broek, J. M. (2016). Citizen science on a smartphone: Participants' motivations and learning. *Public Understanding of Science*, *25*(1), 45–60. https://doi.org/10.1177/0963662515602406

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: advancing the methodology. *Implementation*

Science, *5*(69), 1–9. https://doi.org/doi:10.1186/1748-5908-5-69

Lieberoth, A., Pedersen, M. K., Marin, A. C., Planke, T., & Sherson, J. F. (2014). Getting humans to do quantum optimization - user acquisition, engagement and early results from the citizen cyberscience game Quantum Moves. *Human Computation*, *1*(2), 219–244. https://doi.org/10.15346/hc.v1i2.11

Lieberoth, A., Pedersen, M. K., & Sherson, J. F. (2015). Play or Science? A Study of Learning and Framing in Crowdscience. *Well Played*, *4*(1), 30–55. Retrieved from http://press.etc.cmu.edu/content/volume-4-number-1

Magnussen, R., Hansen, S. D., Planke, T., & Sherson, J. F. (2014). Games as a Platform for Student Participation in Authentic Scientific Research. *Electronic Journal of E-Learning*, *12*(3), 259–270.

Martin, V. Y. (2017). Citizen Science as a Means for Increasing Public Engagement in Science: Presumption or Possibility? *Science Communication*, *39*(2), 142–168. https://doi.org/10.1177/1075547017696165

Michonneau, F., & Paulay, G. (2015). Using iNaturalist to learn more about echinoderms. *Reef Encounter*, *30*(1), 29–31.

Miranda, J., Chavarria-Barrientos, D., Macias, M., Molina, M., Ponce, P., Molina, A., & Wright, P. K. (2017). Experiences in interactive collaborative learning using an open innovation laboratory: The design methodologies course as case study. *2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, 1235–1242. https://doi.org/10.1109/ICE.2017.8280021

Miranda, J., Lopez, C. S., Navarro, S., Bustamante, M. R., Molina, J. M., & Molina, A. (2019). Open Innovation Laboratories as Enabling Resources to Reach the Vision of Education 4.0. *2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, 1–7. https://doi.org/10.1109/ICE.2019.8792595

Moe, R. (2015). Current Issues in Emerging eLearning The brief & expansive history (and future) of the MOOC: Why two divergent models share the same name. *Current Issues in Emerging ELearning*, *2*(1). Retrieved from https://scholarworks.umb.edu/cieeAvailableat:https://scholarworks.umb.edu/ciee/vol2/iss1/2

National Geographic. (2016). *Service Learning: Educator Guide*. https://doi.org/10.5840/tej20131325

National Geographic. (2019a). Field-Based Environmental Service Learning. Retrieved December 18, 2019, from National Geographic website: https://www.nationalgeographic.org/idea/field-based-environmental-service-learning/?utm_source=BibblioRCM_Row

National Geographic. (2019b). Making a Decision about Building a Road in the Amazon. Retrieved December 18, 2019, from National Geographic website: https://www.nationalgeographic.org/lesson/making-decision-about-building-road-amazon/

National Geographic. (2019c). National Geographic Education Resource Library. Retrieved December 17, 2019, from National Geographic website: https://www.nationalgeographic.org/education/resource-library/

National Geographic. (2019d). National Geographic Learning Framework. Retrieved December 17, 2019, from National Geographic Education website: https://www.nationalgeographic.org/education/about/learning-framework/

National Geographic. (2019e). School-Based Environmental Service Learning. Retrieved December 18, 2019, from National Geographic website: https://www.nationalgeographic.org/idea/field-based-environmental-service-learning/?utm_source=BibblioRCM_Row

NRM Education. (2018). *Waterwatch Monitoring Teacher Resource Pack*. Retrieved from https://www.naturalresources.sa.gov.au/samurraydarlingbasin/education/school-programs/water-watch

O'Reilly, C. M., Gougis, R. D., Klug, J. L., Carey, C. C., Richardson, D. C., Bader, N. E., … Hunter, W. (2017). Using large data sets for open-ended inquiry in undergraduate science classrooms. *BioScience*, *67*(12), 1052–1061. https://doi.org/10.1093/biosci/bix118

Oberle, A., Bess, J., Ehmke, K., Rath, S., & Robbins, A. (2019). Geo-Inquiry: Informed Action to Make Our World a Better Place. *The Geography Teacher*, *16*(4), 170–178. https://doi.org/10.1080/19338341.2019.1662467

Open Data Kit. (2019). Open Data Kit. Retrieved December 23, 2019, from http://opendatakit.org/

Open Education Consortium. (n.d.). About The Open Education Consortium. Retrieved November 21, 2019, from Open Education Consortium: The Global Network for Open Education website: https://www.oeconsortium.org/about-oec/

Open Knowledge Foundation. (n.d.). Open Definition 2.1. Retrieved December 3, 2019, from Open Definition website: https://opendefinition.org/od/2.1/en/

Open Science School. (n.d.-a). Co-lab interdisciplinary workshops. Retrieved December 17, 2019, from Open Science School website: http://openscienceschool.org/biocolab/

Open Science School. (n.d.-b). Our Values. Retrieved December 17, 2019, from http://openscienceschool.org/values/

Open Science School. (n.d.-c). The open source modular spectrophotometer. Retrieved December 18, 2019, from Open Science School website: http://openscienceschool.org/spectrophotometer/

OpenSciEd. (n.d.). Inside an OpenSciEd Classroom. Retrieved December 17, 2019, from OpenSciEd website: https://www.openscied.org/instructional-materials/inside-an-openscied-classroom/

OpenSciEd. (2019). *OpenSciEd Teacher Handbook* (Beta Versi). OpenSciEd.

Pandya, R., & Dibner, K. A. (2019). Learning through citizen science: Enhancing opportunities by design. In *Learning Through Citizen Science: Enhancing Opportunities by Design*. https://doi.org/10.17226/25183

Paskevicius, M., & Irvine, V. (2019). Open Education and Learning Design: Open Pedagogy in Praxis. *Journal of Interactive Media in Education*, *2019*(1), 1–10. https://doi.org/10.5334/jime.512

Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., … Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47–61. https://doi.org/10.1016/j.edurev.2015.02.003

Peters, M. A., & Roberts, P. (2016). *The Virtues of Openness: Education, Science, and Scholarship in the Digital Age*. https://doi.org/10.1017/CBO9781107415324.004

Pfueller, S. L., Innes-Wardell, I., Skondras, H., Marshall, D., & Kruger, T. (1997). An Evaluation of Saltwatch: A School and Community Action Research Environmental Education Project. *Australian Journal of Environmental Education*, *13*(4), 61–68. https://doi.org/10.1017/S0814062600002846

Phillips, T. B., Ballard, H. L., Lewenstein, B. V., & Bonney, R. (2019). Engagement in science through citizen science: Moving beyond data collection. *Science Education*, *103*(3), 665–690. https://doi.org/10.1002/sce.21501

Pocock, M. J. O., Chapman, D. S., Sheppard, L. J., & Roy, H. E. (2014). *Choosing and Using Citizen Science*. Retrieved from https://www.ceh.ac.uk/sites/default/files/sepa_choosingandusingcitizenscience_interactive_4web_final_amended-blue1.pdf

Posthumus, E., & Crimmins, T. (2011). Nature's Notebook: A Tool for Education and Research. *Bulletin of the Ecological Society of America*, *92*(2), 185–187. https://doi.org/10.1890/0012-9623-92.2.185

Powell, M. C., & Colin, M. (2008). Meaningful Citizen Engagement in Science and Technology. *Science Communication*, *30*(1), 126–136. https://doi.org/10.1177/1075547008320520

Radchenko, I., & Sakoyan, A. (2016). On Some Russion Educational Projects in Open Data and Data Journalism. In D. Mouromtsev & M. D'Aquin (Eds.), *Open Data for Education* (pp. 153–165). https://doi.org/10.1007/978-3-319-30493-9_8

Raddick, M. J., Prather, E. E., & Wallace, C. S. (2019). Galaxy zoo: Science content knowledge of citizen scientists. *Public Understanding of Science*, *28*(6), 636–651. https://doi.org/10.1177/0963662519840222

Reiser, B. J., Novak, M., & Mcgill, T. A. W. (2017). Coherence from the Students' Perspective: Why the Vision of the Framework for K-12 Science Requires More than Simply " Combining " Three Dimensions of Science Learning. *Board of Science Education Workshop "Instructional Materials for the Next Generation Science Standards,"* 1–11. Retrieved from http://www.nextgenstorylines.org/

Riesch, H., & Potter, C. (2014). Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. *Public Understanding of Science*, *23*(1), 107–120. https://doi.org/10.1177/0963662513497324

Rosen, J. R., & Smale, M. A. (2015). Open Digital Pedagogy = Critical Pedagogy. Retrieved November 20, 2019, from Hybrid Pedagogy: A Digital Journal of Teaching and Technology website: http://www.hybridpedagogy.com/journal/open-digital-pedagogy-critical-pedagogy/

Savino, T., Messeni Petruzzelli, A., & Albino, V. (2017). Search and Recombination Process to Innovate: A Review of the Empirical Evidence and a Research Agenda. *International Journal of Management Reviews*, *19*(1), 54–75. https://doi.org/10.1111/ijmr.12081

Schops, M. (2016). *Stakeholders Needs Regarding Open Data*. Retrieved from http://odedu-project.eu/wp-content/uploads/2017/08/ODEdu_D11_StakeholdersNeedsRegardingOpenData_V1b.pdf

Sharples, M., Aristeidou, M., Herodotou, C., McLeod, K., & Scanlon, E. (2019). Inquiry learning at scale: Pedagogy-informed design of a platform for citizen inquiry. *Proceedings of the 6th 2019 ACM Conference on Learning at Scale, L@S 2019*. https://doi.org/10.1145/3330430.3333642

Simeone, L., Secundo, G., & Schiuma, G. (2017). Knowledge translation mechanisms in open innovation: The role of design in r&d projects. *Journal of Knowledge Management*, *21*(6), 1–28. https://doi.org/10.1108/JKM-10-2016-0432

Smithsonian's National Zoo & Conservation Biology Institute. (n.d.). Example of a Neighborhood Nestwatch lesson plan. Retrieved December 9, 2019, from Neighborhood Nestwatch School Activitiy website: https://nationalzoo.si.edu/migratory-birds/neighborhood-nestwatch-school-participation

Soule, D., Darner, R., O'Reilly, C. M., Bader, N. E., Meixner, T., Gibson, C. A., & McDuff, R. E. (2018). EDDIE modules are effective learning tools for developing quantitative literacy and seismological understanding. *Journal of Geoscience Education*, *66*(2), 97–108. https://doi.org/10.1080/10899995.2018.1411708

Stommel, J. (2014). Critical Digital Pedagogy: a Definition. Retrieved November 20, 2019, from Hybrid Pedagogy: A

Digital Journal of Teaching and Technology website: https://hybridpedagogy.org/critical-digital-pedagogy-definition/

Tecnológico de Monterrey. (2019). Open Innovation Laboratory. Retrieved December 17, 2019, from Open Innovation Laboratory website: http://open-ilab.com/

The Derek Bok Center for Teaching and Learning. (2019). On Learning Goals and Learning Objectives. Retrieved December 10, 2019, from The Derek Bok Center for Teaching and Learning website: https://bokcenter.harvard.edu/learning-goals-and-learning-objectives

The OPAL Initiative. (2011). *Beyond OER: Shifting Focus to Open Educational Practices, OPAL Report 2011*. The OPAL Initiative.

Theriot, S. (2009). Research summary: Service-learning. Retrieved December 18, 2019, from http://www.amle.org/TabId/270/ArtMID/888/ArticleID/323/Research-Summary-Service-Learning.aspx

Thompson, A. L., Strauss, A. L., Oberhauser, K. S., Koomen, M. H., Montgomery, R. A., Andicoechea, J., & Blair, R. B. (2018). *Driven to Discover: Citizen Science Curriculum Guide, Phenology and Nature's Notebook*. Saint Paul, Minnesota: University of Minnesota Extension.

Trumbull, D. J., Bonney, R., Bascom, D., & Cabral, A. (2000). Thinking scientifically during participation in a citizen-science project. *Science Education*, *84*(2), 265–275. https://doi.org/10.1002/(SICI)1098-237X(200003)84:2<265::AID-SCE7>3.0.CO;2-5

Turner, J. (n.d.). Studying Different Genres. In *Panorama*. National Geographic Learning, a Cengage Company.

USA-NPN National Coordinating Office. (2013). *USA National Phenology Network Plant and Animal Observation Handbook*. USA-NPN Education & Engagement Series 2013-001.

USA National Phenology Network. (2019). Nature's Notebook Education Program. Retrieved December 12, 2019, from Nature's Notebook website: https://www.usanpn.org/nn/education

Veletsianos, G., & Kimmons, R. (2012a). Assumptions and challenges of open scholarship. *International Review of Research in Open and Distance Learning*, *13*(4), 166–189. https://doi.org/10.19173/irrodl.v13i4.1313

Veletsianos, G., & Kimmons, R. (2012b). Networked Participatory Scholarship: Emergent techno-cultural pressures toward open and digital scholarship in online networks. *Computers and Education*, *58*(2), 766–774. https://doi.org/10.1016/j.compedu.2011.10.001

Villasclaras Fernandez, E., Sharples, M., Kelley, S., & Scanlon, E. (2013). Supporting Citizen Inquiry: an investigation of Moon Rock. In *Scaling up Learning for Sustained Impact, Lecture Notes in Computer Science* (pp. 383–395). https://doi.org/10.1007/978-3-642-40814-4

Waterwatch Victoria. (n.d.). Run of the River: The Healthy Rivers board game. Retrieved December 13, 2019, from Waterwatch Victoria website: http://www.vic.waterwatch.org.au/cb_pages/education_resources.php

Waterwatch Victoria. (2019). Welcome to Waterwatch Victoria. Retrieved December 10, 2019, from Waterwatch Victoria website: http://www.vic.waterwatch.org.au/cb_pages/welcome_to_waterwatch_victoria.php

Weller, M. (2011). The Digital Scholar: How Technology is Transforming Scholarly Practice. In *The Digital Scholar: Philosopher's Lab* (Vol. 1). https://doi.org/10.5840/dspl2018111

Weller, M. (2014). The Battle for Open: How opennes won and why it doesn't feel like victory. In *The Battle For Open How openness won and why it doesn't feel like victory*. https://doi.org/http:// dx.doi.org/10.5334/bam

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, Modeling, and Metacognition: Making Science Accessible to All Students. *Cognition and Instruction*, *16*(1), 3–118. https://doi.org/10.1207/s1532690xci1601

Wiggins, A., & Crowston, K. (2011). From conservation to crowdsourcing: A typology of citizen science. *Proceedings of the Annual Hawaii International Conference on System Sciences*, 1–10. https://doi.org/10.1109/HICSS.2011.207

Wiley, D. (n.d.). Defining the "Open" in Open Content and Open Educational Resources. Retrieved November 21, 2019, from opencontent.org website: http://opencontent.org/definition/

Wiley, D. (2006). *Expert Meeting on Open Educational Resources*. Organisation for Economic Co-operation and Development, Centre for Educatonal Research and Innovation.

Wiley, D. (2009). Defining "Open." Retrieved November 21, 2019, from Iterating Towards Openness website: https://opencontent.org/blog/archives/1123

Wiley, D., Bliss, T. J., & McEwen, M. (2014). Open Educational Resources: A Review of the Literature. In S. J., M. M., E. J., & B. M. (Eds.), *Handbook of Research on educational Communications and Technology* (pp. 781–789). https://doi.org/10.1007/978-1-4614-3185-5

Wiley, D., & Hilton, J. (2018). Defining OER-Enabled Pedagogy. *International Review of Research in Open and Distributed Learning*, *19*(4).

Winn, J. (2012). *Open Education: From the Freedom of Things to the Freedom of People* (M. Neary, H. Stevenson, & L. Bell, Eds.). Retrieved from http://eprints.lincoln.ac.uk/4064/

Xu, Y., & Maitland, C. (2019). Participatory data collection and management in low-resource contexts: A field trial with urban refugees. *ACM International Conference Proceeding Series*, (April). https://doi.org/10.1145/3287098.3287104

Zotou, M., Panopoulou, E., Karamanou, A., Tambouris, E., Konstantinos, T., & Skov, M. (2018). *University pilots report*. ODEdu: Open Data Education.

Zourou, K., & Tseliou, A. (2020). *Academia permeating society through Citizen Science: Recommendations for Higher Education Institutions.* INOS Consortium. Retrieved from https://inos-project.eu/

Annex A – Outlines of selected case studies

The following case studies are in alphabetical order.

1 A Scuola di OpenCoesione

Website: http://www.ascuoladiopencoesione.it/en

Outline: "ASOC is about civics, digital skills, statistics and storytelling, but also about cross-functional skills such as critical thinking, problem solving, teamwork, and interpersonal and communication skills.

This educational programme is organised in four lessons that include an on-site civic monitoring visit, events to be organised during the Open Government Week, and a final public event. The syllabus is organised based on a mixed model that includes both massive open online course (MOOC) and project-based working groups using social networking, blogging, and online sharing activities.

Participation in the project is open to students of all types of secondary schools (high schools), who participate in teams (i.e. entire classes, smaller groups within a class, or groups of students from different classes) that may have up to 25 students.

The teams involved in the project are guided by the main teacher, eventually supported by a second teacher.

Each team carries on a research work on a specific theme starting from a project financed by cohesion policies. This project is to be selected based on data published on the OpenCoesione webportal in order to assess how public policies are working to improve the local community.

The ASOC educational programme contents can be used as a part of a work-study programme for approximately 50 hours of activity.

Teachers who participate to the project are offered 25-hour training programmes recognised by the Italian Ministry of Education."

Taken from: http://www.ascuoladiopencoesione.it/en/content/educational-programme

2 air:bit

Website: http://airbit.uit.no/

Outline: "We have developed the air:bit, an Arduino-based air quality sensor kit that students build and program to collect air quality data in their local environment. Together with the air:bit sensor kit, we developed teaching materials that include how to assemble the air:bit and how to program its different sensors, and a cloud based service for students to upload and explore their collected datasets. All of which are openly available online at airbit.uit.no. We used these resources [to] develop an interdisciplinary course for students in Norwegian upper secondary schools, which we offered to different schools across Northern Norway" (Fjukstad et al., 2018).

3 Alan Walks Wales Dataset

Website: https://alanwalks.wales/

Outline: "This case study describes the educational use of an open dataset collected as part of a thousand mile research walk. The content connects to many hot topics including quanti2ed self, privacy, biosensing, mobility and the digital divide, so has an immediate interest to students. It includes inter-linkable qualitative and quantitative data, in a variety of specialist and general formats, so offers a variety of technical challenges including visualisation and data mining as well. Finally, it is raw data with all the glitches, gaps and problems attached to this" (Dix & Ellis, 2015).

At the end of each school year, the best teams take part in a final event in Rome, in which the entire community is rewarded."

Taken from: http://www.ascuoladiopencoesione.it/en/content/about-asoc

4 BOKUroadkill

Website: https://roadkill.at/en/ (website for Project Roadkill, the subsequent version of BOKUroadkill extended for all citizens instead of just university students)

Outline: "Many European universities are faced with increasing student numbers along with unchanged numbers of advising lecturers and professors. Thus, a challenge for natural science educators is to teach and transfer knowledge despite weak lecturer-to-student ratios. In search for a solution to this problem, we applied a citizen science crowdsourcing approach in an obligatory course of the Bachelor programme of Environment and Bio-Resources Management at the University of Natural Resources and Life Sciences Vienna, Austria. The project, called BOKUroadkill, engaged students in reporting roadkilled animals they observed during their daily routine over a period of three months. Data collection was carried out via a freely available, customized mobile app (EpiCollect) that ran on students' private devices or via an additional online reporting form for students without smartphones or tablets. After three months, 109 students reported 1,236 animals killed on roads, analysed roadkill patterns, and provided feedback on the project" (Heigl & Zaller, 2014).

5 Challenge Based Innovation @IdeaSquare

Website: https://www.cbi-course.com/

Outline: "Challenge Based Innovation is a 4-6 months programme where teams of university students develop projets that solve complex societal problems, inspired by technological ideas that come from instrumentation development or basic research at CERN… In CBI student teams work with CERN, one of the world's leading research centres in particle physics, for the purpose of making disruptive innovation for societal impact… Here students apply their hard skills to challenging projects, in an entrepreneurial setting. They work in a multidisciplinary team, develop their critical thinking and get hands-on to make their ideas real through prototyping and testing."

Taken from: https://www.cbi-course.com/

6 City Nature Challenge

Website: http://citynaturechallenge.org/

Outline: "Started in 2016 for the first-ever Citizen Science Day, the citizen science teams at Natural History Museum of Los Angeles County and California Academy of Sciences dreamed up the City Nature Challenge as a fun way to capitalize on their home cities' friendly rivalry and hold a citizen science event around urban biodiversity. The first City Nature Challenge was an eight-day competition between Los Angeles and San Francisco, engaging residents and visitors in documenting nature to better understand urban biodiversity. Over 20,000 observations were made by more than 1000 people in a one-week period, cataloging approximately 1600 species in each location, including new records for both areas. During the 2016 CNC, we heard so much excitement and interest from people in other cities that we decided we couldn't keep to the fun just to ourselves. In 2017 the City Nature Challenge went national, and in 2018, the CNC became an international event!"

Taken from: http://citynaturechallenge.org/about/

7 Eesti otsib nurmenukke [Estonia is Looking for Primroses]

Website: https://www.nurmenukk.ee/

Outline: "Koos Tartu Ülikooli teadlaste ja Eestimaa Looduse Fondiga kutsume sel kevadel liituma ühe põneva kodanikuteaduse algatusega – Eesti otsib nurmenukke! Üle-eestilise kaardistamisega on plaan koguda teadustööks vajalikud andmed üle Eesti vaid paari nädalaga, mil nurmenukud kevadel õitsevad... Eelteadmisi pole vaja. Nurmenukutalgutel võib osaleda igaüks! Vaatluse läbiviimiseks on vaja silmata ühes kasvukohas saja taime õisi ning märkida nutiveebi abil, kas tegu on S-tüüpi või L-tüüpi nurmenukuga."

Taken from: https://www.teemeara.ee/talgujuhile/nurmenukutalgud

8 iSCAPE Living Labs

Website: https://livinglabs.iscapeproject.eu/

Outline: "ISCAPE Living Labs study, test and implement design and technology interventions to improve the air quality of our cities. For example, ISCAPE Living Labs are interested in assessing the potential of low boundary walls, trees and hedge-rows, green walls and roofs, photocatalytic coatings, low-cost sensing kits, green urban spaces and road geometry interventions. ISCAPE Living Labs are not only a technology-driven endeavour, but they are also aimed at directly involving citizens and city stakeholders and promoting behavioural change. All this is going to be tested in six European cities between 2017 and 2019.

The ISCAPE Living Labs website will gather the results of these tests and present opportunities for collaboration and concrete solutions that we all can apply to improve the air quality of our cities.

The ISCAPE Living Labs website is targeted at all the people and organisations involved in the six Living Labs, to architects, urban planners and makers of citizen sensors as well as to all who are interested to improve air quality in cities. It will contain, among others, an interactive air quality map connected to the sensors deployed during ISCAPE, interactive tutorials on how to set up and use the sensors and toolkits for practitioners based upon key learnings. These will be included as soon as the sensors are ready to be used or when results are ready to be disseminated.”

Taken from: https://livinglabs.iscapeproject.eu/about/

9 Masseeksperiment 2019

Website: https://naturvidenskabsfestival.dk/masseeksperiment

https://naturvidenskabsfestival.dk/tildinundervisning/masseeksperiment-2019-plastforurening-i-vand

Outline: “Masseeksperimentet 2019 er verdens første nationale kortlægning af plastforurening. Sammen skal vi undersøge, hvor i Danmark der findes plastaffald, hvilke kategorier af plastaffald der findes, og hvilke polymerer plastaffaldet består af… Kilderne til plastforurening er mange - det kan være fra private husholdninger, industrien, landbruget, fiskeriet og når vi som forbrugere smider plastaffald fra os i naturen. Men vi har ikke tilstrækkelig viden om omfanget af plastforureningen, ligesom vi ikke ved nok om, hvilken slags plast vi finder derude, og hvor den findes henne… Eleverne skal med naturvidenskabelige undersøgelsesmetoder (indsamling, sortering, identifikation og registrering) kortlægge et stykke dansk natur for plastaffald, og derefter bestemme mængden og typen af plast, de har fundet. Desuden kan eleverne, med 'low key' identifikationsmetoder, bidrage med undersøgelser af det plastaffald, de finder - hvilke polymerer består plastaffaldet af? Denne sidste del af eksperimentet er ikke obligatorisk.”

Taken from: https://naturvidenskabsfestival.dk/tildinundervisning/masseeksperiment-2019-plastforurening-i-vand

10 National Geographic Education

Website: https://www.nationalgeographic.org/education/

Outline: “Our Resource Library offers high-quality, standards-based, educational resources and activities. Many of our free maps, lesson plans, imagery, interactives, and reference materials have been curated into collections grounded in the bold and transformative approach that National Geographic takes around science, exploration and storytelling.”

Taken from: https://www.nationalgeographic.org/education/

11 National Institute of Invasive Species Science (NIISS) educational program

Website: http://ibis.colostate.edu/cwis438/websites/niiss/Home.php?WebSiteID=1

Outline: “The National Institute of Invasive Species Science (NIISS; see www.citsci.org) is a consortium of government and non-government organizations formed to develop cooperative approaches for invasive species research that meet the needs of multiple stakeholders. In 2006, the organization began to develop a national citizen science program to effectively coordinate data collection efforts among scientists, natural resource managers, and the public… As part of the NIISS program, staff developed training presentations and related educational materials that could be easily adopted by existing volunteer organizations. These were divided into four modules (30–45 minutes each), providing flexibility to meet the diverse needs of pro- gram participants. The goals of the training were to: 1) educate participants on invasive species, their threats, and what people can do to stop their spread; 2) teach global positioning systems (GPS) and their uses; and 3) teach tested monitoring protocols that can be used to answer local research questions of interest while facilitating the adoption of standardized data collection methods for addressing research questions at broader spatial scales" (Crall et al., 2012).

12 Nature's Notebook

Websites: https://www.usanpn.org/natures_notebook

Outline: "Nature's Notebook is an off-the-shelf program appropriate for scientists and non-scientists alike, engaging observers across the nation to collect phenology observations on both plants and animals.

Nature's Notebook gathers information on plant and animal phenology across the U.S. to be used for decision-making on local, national and global scales to ensure the continued vitality of our environment.

Scientists alone cannot collect enough data: They need your help. Join more than 15,000 other naturalists across the nation in taking the pulse of our planet. You'll use scientifically-vetted observation guidelines, developed for over 1000 species, to ensure data are useful to researchers and decision-makers."

Taken from: https://www.usanpn.org/nn/about

13 Neighborhood Nestwatch

Website: https://nationalzoo.si.edu/migratory-birds/neighborhood-nestwatch

Outline: "This Smithsonian citizen science program provides an outdoor educational experience for backyard wildlife enthusiasts and underserved youth. Participants contribute to important scientific research by re-sighting banded birds and monitoring nests. The Neighborhood Nestwatch approach features face-to-face interaction on an annual basis between Smithsonian scientists, participants and neighborhood birds. The program takes place in metro-area backyards, as well as at under-resourced schools in cities throughout the U.S."

Taken from: https://nationalzoo.si.edu/migratory-birds/neighborhood-nestwatch

14 nQuire

Website: https://nquire.org.uk/

Outline: "nQuire is a platform to explore yourself and your world. It has been developed by The Open University in partnership with the BBC.

You can take part in two types of nQuire mission.

Confidential missions are surveys to find out more about yourself. We will publish the overall results of each mission on the nQuire platform, but we will never show or share your personal data.

Social missions are open explorations of your world. You can see and discuss each contribution, and the data are available for anyone to view and download.

Each mission has a 'big question' that can only be answered with your help. You will be given instructions about what to do and feedback on your contribution once you complete the mission.

In the future, nQuire will allow anyone to propose a new mission and run it for people around the world to contribute. A topic could be psychology, health, technology, media, animals or plants. All missions will be checked before they go live, to make sure they are safe and legal. As a mission author, you become a citizen scientist recruiting members of the public to take part in experiments and surveys."

Taken from: https://nquire.org.uk/about

15 Ocean i3

Website: https://euskampus.eus/en/programmes-en/euskampus-bordeaux/ocean-i3

Outline: "Ocean I3 Project is focused on the challenge "oceans plastic pollution" and its mission is to contribute to the reduction of pollution on the Basque-Aquitaine transboundary coast. The name Ocean i3 reflects on the 3 "i" in Basque language: Ikaskuntza/Learning-Ikerkuntza/Research-Iraunkortasuna/Sustainable Development.

It is an educational innovation project that seeks to develop transversal competences of university students based on Research Based Learning methodologies and challenges oriented to the 2030 Sustainable Development Goals (RBL-ODS).

Ocean i3 adopts the "Mission-Oriented Research and Innovation" approach (Mazzucato, 2018), and Civic University (Godard, 2012) approach. Student's research projects and practices are oriented to the proposed mission mobilizing collaboration and co-construction of knowledge as well as solutions in close collaboration with territorial agents from the public, private and civil society sectors. The competences being developed, amongst others, have to do with interdisciplinarity, cross-sectoral approaches, systemic and integrated focus of problems, integration of ODS values as well as skills to be able to manage intercultural and multilingual situations."

Taken from: https://euskampus.eus/en/programmes-en/euskampus-bordeaux/ocean-i3

16 ODEdu: Open Data Education

Website: http://odedu-project.eu/

Outline: "Open Data initiatives worldwide are boosting with an aim to increase transparency and contribute to economic growth. With a global annual economic potential value estimated to $3 trillion, this boost seems justified. Current progress however is not satisfactory. We believe a main reason is the lack of relevant skills and competencies. Indeed, current education and training activities are scarce and do not exploit practice-oriented learning methods such as Problem Based Learning (PBL).

As a result, public servants are missing skills related to publishing open data. Similarly, companies and entrepreneurs are missing skills related to re-using open data while students are not provided with sufficient and properly-structured academic courses.

The project aims to establish a Knowledge Alliance between academia, business and the public sector that will boost Open Data education and training. The Alliance will follow a four-dimensional approach, tackling pedagogical, technological, content and application objectives. The consolidation of all efforts will provide a transnational set of results, as follows:

- a novel learning model based on PBL and learning analytics, termed Data Driven PBL
- an open-source platform to support flexible learning pathways and course re-design
- co-created, freely available for any use, multimodal content on Open Data
- innovative activities in academia, businesses and the public sector.

The production of the aforementioned robust results and their lasting application in all three sectors will aim to support the sustainability of a European Open Data learning ecosystem."

Taken from: http://odedu-project.eu/

17 Open Data School Russia

Website: http://opendataschool.ru/

Outline: "Школа открытых данных – это серия лекций и семинаров, а также организация регулярных занятий с ведущими мировыми и российскими экспертами по тематике открытых данных.

В настоящее время, прежде всего в связи с глубоким проникновением сети Интернет, объём общедоступной открытой информации растёт лавинообразно. Возникла острая необходимость научиться распоряжаться уже имеющейся информацией.

Современные государства — крупнейшие создатели и владельцы информации, затрагивающей интересы всего общества. Информационное общество возможно, когда такая информация становится доступна гражданам.

Открытость государственного управления – общемировой тренд последних лет. Фундаментом, на котором строится открытое государство, являются открытые данные — одно из самых динамичных, стратегических направлений развития. С появлением государственной политики в области открытых данных в России, мы ожидаем бум использования гражданами открытых данных и в нашей стране. Умение работать с массивами данных остро востребованы специалистами в самых разных областях – и в госуправлении, и в журналистике, и в экономике. Для работы с открытыми данными нужны специальные знания специальные образовательные курсы по основам программирования, умение анализировать полученную информацию и визуализировать её, и именно таким проектов является Школа Открытых Данных.

Профессиональные разработчики веб- и мобильных приложений, информационных систем и продуктов, широкий круг активных граждан, заинтересованных в развитии гражданского общества, студенты ВУЗов, работники СМИ, политологи, аналитики, исследователи, государственные служащие, подрядчики в области ИТ, некоммерческие организации, овладевшие умением оперировать открытыми данными, принесут пользу обществу в самых разных сферах жизни."

Taken from: http://opendataschool.ru/project/about/

18 Open Innovation Laboratories @Tecnológico de Monterrey

Website: http://open-ilab.com/

Outline: "The Open Innovation Laboratory promotes the development of Sensing, Smart and Sustainable solutions to support the design community of companies and schools through the entire product development lifecycle.

This Open Innovation Laboratory provides interactive spaces and virtual infrastructure to promote the multidisciplinary participation of students and considering the participation of external actors from other academic institutions, companies, government and even from society. The Open Innovation Laboratory at Tecnológico de Monterrey is comprised of three main components (i) innovative learning methods, (ii) design methodologies, and (iii) the rapid product realization platform which includes physical, virtual and remote laboratories."

Taken from: http://open-ilab.com/

19 Open Science School, Paris

Website: http://opensciencesschool.org/

Outline: "Open Science School (referred as "OSS") is a community, which is physically based in the Center for Research and Interdisciplinarity of Paris and expands its actions in a worldwide level. Open Science School was founded at the Center for Research and Interdisciplinarity of Paris in 2014 with the initial purpose of using the potential of synthetic biology as a pedagogic tool for high school students.

OSS aims at testing and developing new models for research, long-life learning, and innovation. From an organizational point of view, OSS is a democratic, and inclusive organization based on the Rochdale principles for co-operative societies (see more at the end of the page). The view of OSS about research and science are based on the Global Open Science Hardware manifesto (see more at the end of the page), open hardware, and open science principles.

OSS advocates for a change of policy in existing educational and research institutions, to shift towards a more open model to create and share innovation. OSS develops long-life learning curricula and spaces that encourage people from different backgrounds to collaborate and co-create, taking advantage of their diversity. We acknowledge that the problems science aims at resolving are beyond the reach of scientists alone, and realize that science is embedded in a culture that we need to consider when defining scientific facts and creating new knowledge or innovations. To summarize: 'Open Science School aims at changing the way we learn using non-conventional approaches'".

Taken from: http://openscienceschool.org/values/

20 OpenSciEd

Website: https://www.openscied.org/

Outline:

- "OpenSciEd was launched to improve the supply of and address demand for high-quality, open-source, full-course science instructional materials, while at the same time supporting the implementation of middle school science instructional units.
- The goals of OpenSciEd are to ensure any science teacher, anywhere, can access and download freely available, high quality, locally adaptable full-course materials.

- OpenSciEd aims to create a set of exemplary science instructional materials that are:
    - designed and aligned to the Framework and NGSS;
    - based on research regarding how students learn, what motivates learning, and the implications for teaching;
    - developed with educators and extensively tested by teachers and schools;
    - designed to be used with low-cost, standard laboratory equipment and materials amenable to large-scale deployment; and
    - improved over time based on feedback from teachers and field-testing.
- While starting at the middle school level, the goal is to create an entire science curriculum from elementary to high school."

Taken from: https://www.openscied.org/about/

21 Project EDDIE: Environmental Data-Driven Inquiry and Exploration

Website: https://serc.carleton.edu/eddie/index.html

Outline: "Scientists are increasingly using sensor-collected, high-frequency and long-term datasets to study geological and environmental processes. Our interdisciplinary team of faculty and research scientists has developed flexible classroom modules that aim to expose undergraduate students to such real-world experiences. These modules utilize large, long-term, high-frequency and sensor-based datasets that can be used in a variety of introductory, mid-level, and advanced courses that meet a series of pedagogical goals, allowing students to: (i) manipulate large datasets to conduct real-world, inquiry-based investigations; (ii) develop reasoning about statistical variation; and (iii) become excited about first-hand experiences with the scientific process. Each module requires students to collect data from online sources, such as discharge and water quality data from the US Geological Survey, ecosystem carbon dioxide flux data from FLUXNET, lake temperature data from the Global Lake Ecological Observatory Network, and seismic data from the Incorporated Research Institutions for Seismology."

Taken from: https://serc.carleton.edu/eddie/enviro_data/index.html

22 Rwanda refugee data program

Website: None available

Outline: "Similar to many data science education initiatives, training low resource communities in data system design, including collection and basic analytic techniques, is a complex and multifaceted undertaking. Here, we report on an effort to introduce and test a participatory data system design process with urban refugees living in Rwanda. Most of the refugees are newly settled. In order to gain familiarity with their community and to be aware of the resources within it, refugees may benefit from defining, collecting and managing these data themselves: they can determine which data in the community they find interesting. This methodology is implemented in practice by actively engaging participants throughout the whole process of data inventory design, data collection, data analysis, and data management. The goal is to promote participants' awareness of their community while gaining skills in collecting and using data. More importantly, unlike the majority of technology-based humanitarian efforts, which position participants as passive users of a given technology, we engage them in co-designing the data management system, including data collection forms, to reflect their interests, as well as how to ethically collect and utilize such data. This study incorporates lessons from a pilot conducted with Za'atari camp refugees in Jordan. Both studies aimed to support community development that focuses on producing empowered" (Xu & Maitland, 2019).

23 Science at Home's Quantum Moves games

Website: https://www.scienceathome.org/games/quantum-moves-2/

Outline: "Quantum Moves 2 is a gamified citizen science project in the field of quantum physics and hybrid-intelligence. The challenge is transferring atoms in the best possible way from a specified initial state to the desired target state within very short timescales (sub-milliseconds) in a quantum laboratory. In the world of quantum physics, this is the complex task called quantum optimal control. The idea of the game is quite simple: in every gameplay, the mouse movements simulate the movement of laser beams used in quantum labs to control and transfer atoms. Every gameplay creates a solution which appears on our end as data describing the movement of the laser beam and quality of the solution. The challenges in the game are based on cutting-edge research problems in quantum computing and quantum matter-wave optics."

Taken from: https://www.scienceathome.org/games/quantum-moves-2/about-quantum-moves-2/

24 Waterwatch/Saltwatch/Estuarywatch programs by Waterwatch Victoria

Website: http://www.vic.waterwatch.org.au/

Outline: "Waterwatch Victoria is a successful community engagement program connecting local communities with river health and sustainable water issues and management since 1993… Celebrating 25 years in 2018, the Victorian Waterwatch Program has been connecting local communities with waterway health and sustainable water management issues. Through the Waterwatch Program, citizen scientists are supported and encouraged to become actively involved in local waterway monitoring and onground activities."

Taken from: http://www.vic.waterwatch.org.au/cb_pages/welcome_to_waterwatch_victoria.php